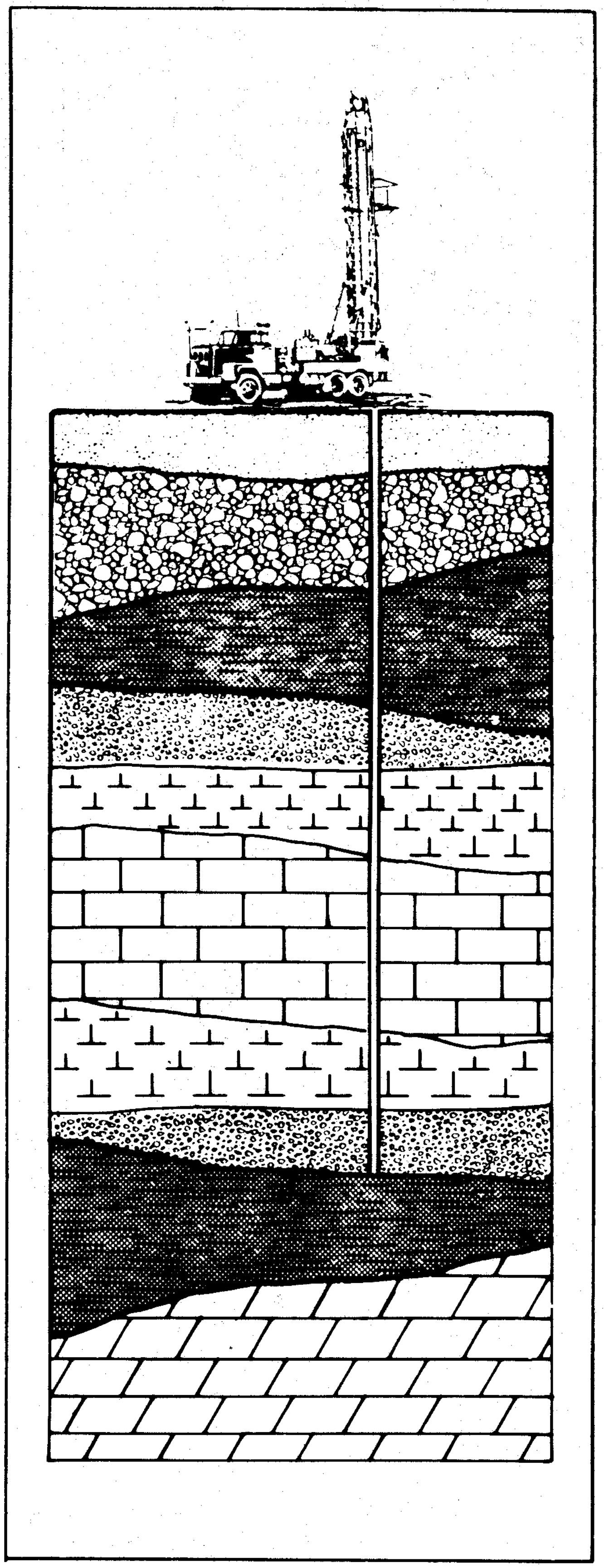
Rec'd 3 July 84 EWR



GROUNDWATER RESOURCES OF HENRICO COUNTY, VIRGINIA

PRESENT CONDITIONS AND PROSPECTS

by

Haywood A. Wigglesworth
Timothy W. Perry
Russell P. Ellison III

PIEDMONT REGIONAL OFFICE

COMMONWEALTH OF VIRGINIA

STATE WATER CONTROL BOARD

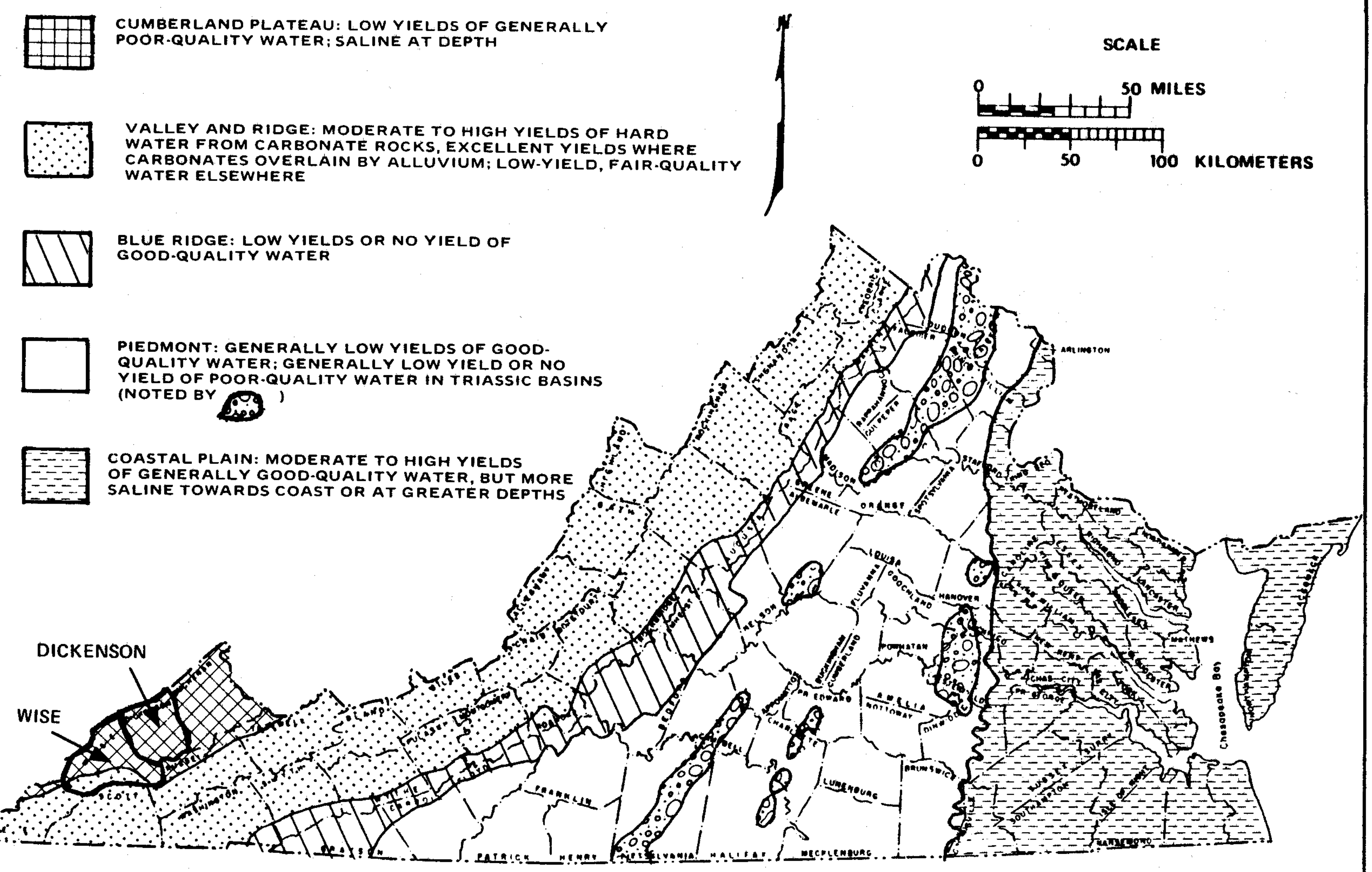
BUREAU OF SURVEILLANCE AND FIELD STUDIES

Richmond, Virginia

Planning Bulletin 328

March 1984

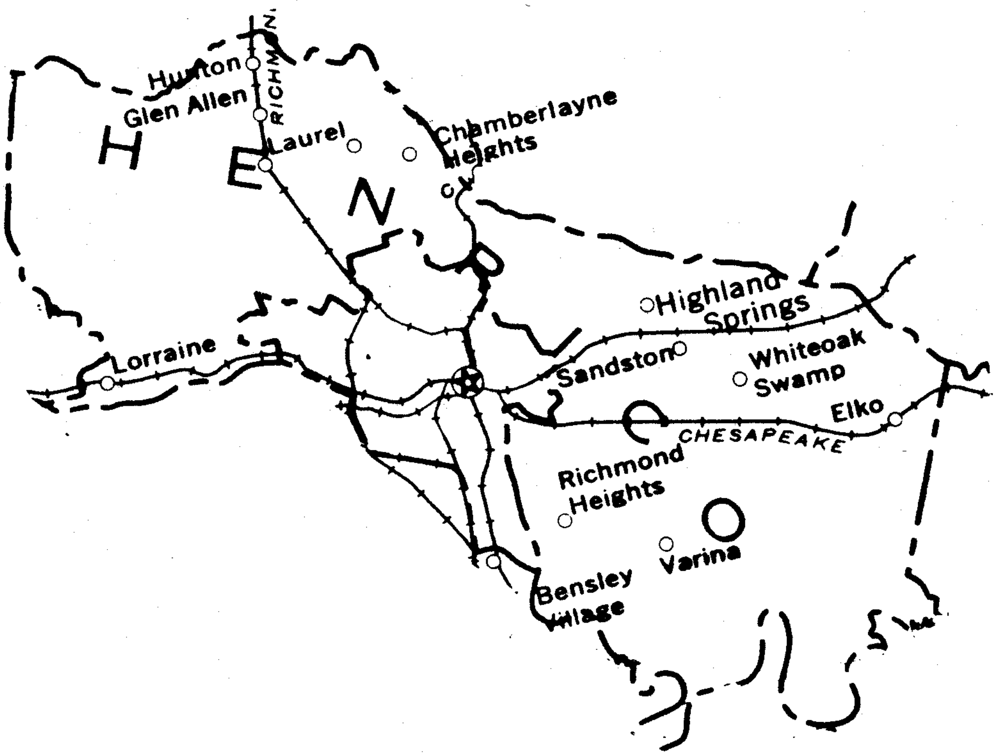
GROUND WATER CHARACTERISTICS OF THE PHYSIOGRAPHIC PROVINCES IN VIRGINIA



Source: Virginia State Water Control Board — BWCM

Frontispiece

GROUND WATER RESOURCES OF HENRICO COUNTY, VIRGINIA



by

Haywood A. Wigglesworth

Timothy W. Perry

Russell P. Ellison III

PIEDMONT REGIONAL OFFICE

STATE WATER CONTROL BOARD

BUREAU OF SURVEILLANCE AND FIELD STUDIES

Richmond, Virginia

Planning Bulletin No. 328

FOREWORD

This report is one of a series intended to inventory the ground water resources of each county in the Commonwealth. The purpose is to provide all ground water users, including private citizens, developers, investors, well drilling contractors, government officials, professionals and consultants, with an overview of the ground water situation as it presently exists throughout Virginia.

It is our intent that prospective ground water users and others interested in the development and protection of ground water will gain insight into the opportunities and advantages inherent in this invaluable natural resource.

The State Water Control Board remains available for information, assistance and governmental action.

ACKNOWLEDGEMENTS

The Office of Geology at the Piedmont Regional Office of the State Water Control Board is indebted to many individuals who made this ground water report possible.

We are indebted to the Virginia Division of Mineral Resources for our understanding of the geology of Henrico County. Their excellent publications, supplemented by the current work produced by Gene Rader and his staff, have proven invaluable.

We are grateful to the many water well drillers operating in the Piedmont Region who supplied us with water well data. The most informative of these companies include Sydnor Hydrodynamics, Mitchell's Well and Pump Company, Dowdy's Well and Septic Service, W. H. Gammon Well Drilling, and Mathews Well and Pump Company.

The assistance of our fellow State Water Control Board employees was vital to the production of this publication. Rick Bower and Al Giles supplied hydrogeologic expertise, Craig Churn provided the necessary computer assistance, and Bill Banks and Ed Adams of the Drafting and Reproduction Department provided the graphic skills for the illustrations.

We appreciate the efforts of the many people who took the time to review the preliminary draft of this report. These include our fellow State Water Control Board Regional Geologists, Herb Hopkins of the U.S. Geological Survey, John Benko of the Henrico County Health Department, Garland Sydnor of Sydnor Hydrodynamics, and Timothy McGarry of the Richmond Regional Planning District Commission.

Special thanks are due to our patient secretary, Nancy Thurston, whose typographical perfection and command of the English language have contributed immensely to the coherence of this report.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

SELECTED CONVERSION FACTORS
ENGLISH UNITS TO INTERNATIONAL SYSTEM (METRIC UNITS)

This report uses a dual measurement system based on English units and the International System (SI) of metric units. SI is a consistent system of units adopted in 1960 by the Eleventh General Conference of Weights and Measures. Selected conversion factors are listed below:

Multiply English Units	By	To Obtain SI Units
Acres	0.4047	hectares
Feet (ft)	0.3048	metres (m)
Gallons	0.003785	cubic metres (m^3)
Gallons per day (gpd)	0.003785	cubic metres per day (m^3/d)
Gallons per minute (gpm)	0.06309	litres per second (l/s)
Inches	25.4	millimetres (mm)
Miles	1.609	kilometres (km)
Million gallons per day (MGD)	3,785.0	cubic metres per day (m^3/d)
Square miles	2.590	square kilometres (km^2)

GROUND WATER RESOURCES OF HENRICO COUNTY, VIRGINIA

BY

Haywood A. Wigglesworth, Timothy W. Perry, and
Russell P. Ellison, III

ABSTRACT

Henrico County is centrally located along the Fall Zone in Virginia and encompasses portions of both the Piedmont and Coastal Plain Physiographic Provinces. The geologic diversity between the provinces, as well as geologic differences within each, produces a complex system for ground water recharge, storage and retrieval.

The Piedmont section of Henrico County is composed primarily of crystalline rocks which contain little water except in areas of fracturing and faulting. The crystalline rocks are overlain by a thick zone of weathered bedrock which serves as a shallow aquifer system for many low demand purposes.

The Coastal Plain section of Henrico County is comprised of an eastward-thickening sequence of sedimentary deposits ranging in age from the Cretaceous Period (135-65 MYBP) to the present. The major aquifer in the Coastal Plain is the Patuxent Formation which rests upon the crystalline bedrock. The Patuxent is comprised primarily of coarse sand and gravel and is the best water producing unit in the county. Above the Patuxent is a series of geologic units which were deposited during episodes of advance (transgression) and retreat (regression) of the sea. These units are often unfavorable for high-yield purposes due to a large clay content.

Ground water quality in Henrico County is generally good although localized problems do exist. Care should be taken in the construction of water wells to properly seal off the aquifer from sources of contamination. Shallow, water table aquifers are particularly susceptible to contamination from surface sources such as fertilizer, lagoons, fuel storage tanks and failing septic fields.

Well systems owned by Henrico County withdraw approximately 6.06 million liters (1.6 million gallons) of ground water per day at present. With the addition of new wells to the system, this figure is expected to double within the next five to ten years. Increased ground water withdrawals from the Patuxent Formation are possible without seriously depleting the aquifer; however, consideration should be given to the needs of the counties to the east which also tap the Patuxent Formation.

CHAPTER I

INTRODUCTION

Purpose and Scope of Report

This report is designed to acquaint the public with the latest information on the location, quality, quantity, and future use potential of the ground water resources of Henrico County and that part of the City of Richmond which is north of the James River. It is intended to be an aid to the private citizen, government agencies, developers, county and city planners, well drilling contractors, and all others interested in the location, development, utilization and protection of the ground water of Henrico County and the City of Richmond.

Much basic information, as well as detailed scientific data, has been combined in this report in order that the layman, as well as the professional, may be assisted.

Geology and ground water do not recognize political boundaries. Therefore, for simplicity, "Henrico County" or "county", as used in this report, includes the City of Richmond north of the James River.

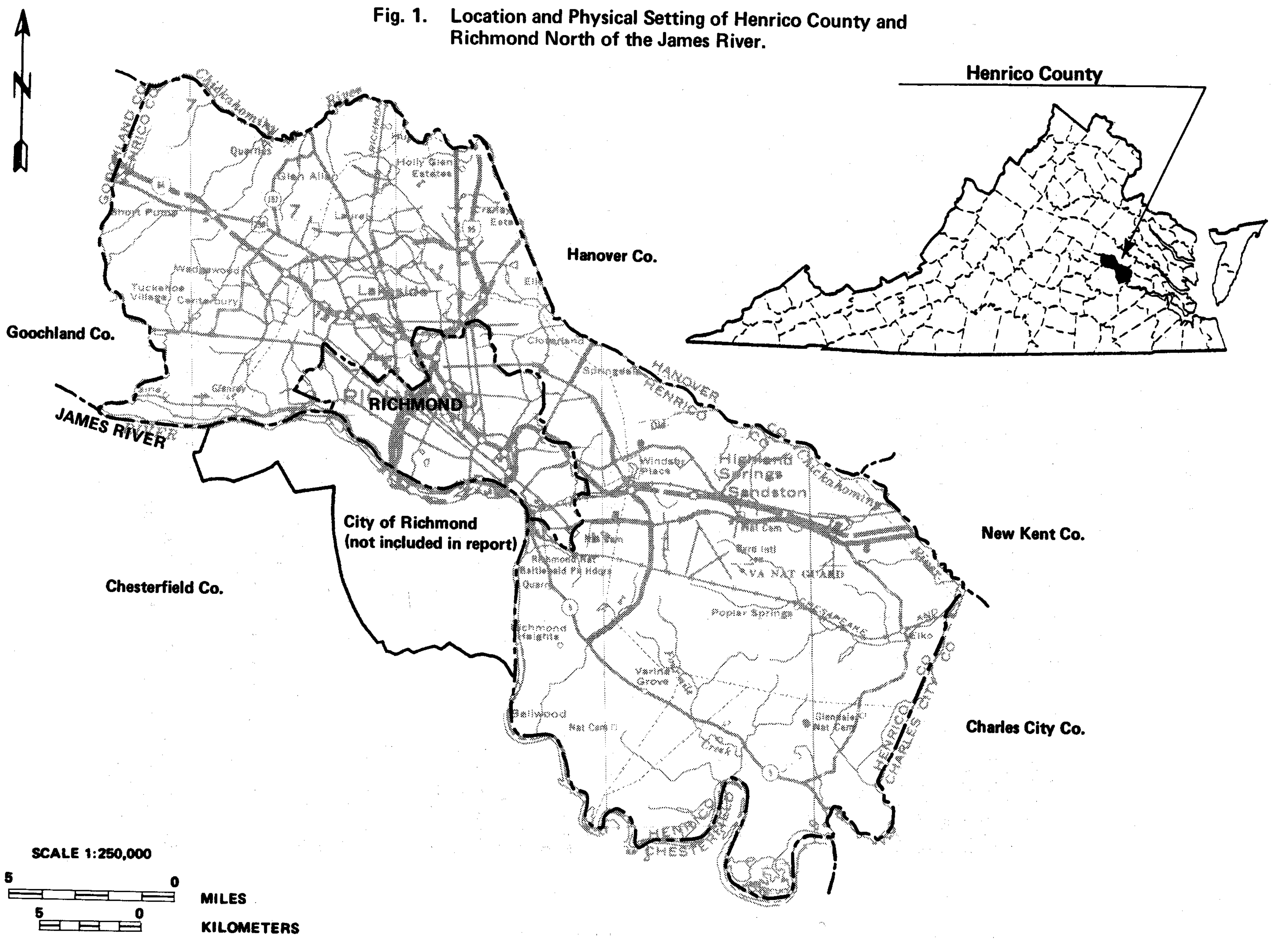
Introduction

One of the original eight shires or counties formed in 1734, Henrico County has a history almost as long as that of the State itself. Settlement in the county began as early as 1611 and the county has been the scene of many important events in the State's history. Originally encompassing all or part of eleven present day counties, Henrico County has been decreased in size to approximately 637 square kilometers (245 square miles). The portion of Richmond north of the James River covers approximately 69 square kilometers (26 square miles), and was formerly a part of Henrico County.

The county is located in east-central Virginia and is bounded on the north by Hanover and New Kent Counties, on the east by Charles City County, on the south by Chesterfield County and the James River, and on the west by Goochland County. [Figure 1] The county is partly bounded by the Chickahominy River to the north-northeast and the James River along its entire southern border. Much of the county's western boundary is made up by Tuckahoe Creek. Turkey Island Creek comprises much of the county line in the southeast.

In 1978 the U.S. Bureau of Census reported that 147,791 people lived in the City of Richmond north of the James River. The 1980 U.S. Census figures place the population of Henrico County at 180,315 people.

Fig. 1. Location and Physical Setting of Henrico County and Richmond North of the James River.



SOURCE: State Water Control Board – P.R.O.

Method of Investigation and Data Assembly

The background information for this report was acquired from previous regional, State, and county reports. Much of the census and economic data were collected from city and county officials and other State agencies.

Information on the climate, soils, and vegetation came from specialized county and regional reports. Surface water (runoff and drainage) information was supplied by the State Water Control Board (SWCB).

The pertinent geologic and geohydrologic data were collected by the Bureau of Water Control Management of the State Water Control Board, Piedmont Regional Office. Rules and standards of the State Water Control Board have provided for such data collection by requiring a Water Well Completion Report (Form GW-2) to be submitted to the Board for each newly constructed water well (Appendix 1). This water well completion report provides a record of the location, owner, contractor, construction data, screen location, water level, yield, pump data, and driller's log for the well. Geophysical logs are not required, but are a great aid in geohydrologic interpretation when provided. Each water well completion report must be accompanied by well cuttings collected for each 10 feet of depth drilled unless previous exemption is secured from the State Water Control Board. Sample bags for the cuttings are provided free by the Bureau of Water Control Management in Richmond. Also, all industrial and public supply water well users are required to submit a Ground Water Pumpage and Use Report (Form GW-6) to the Board quarterly (Appendix 1).

To provide for better ground water data management and pollution protection, the State Water Control Board requires that it be informed of all wells which are to be abandoned temporarily or permanently. When an industrial or public water supply well is to be abandoned, the owner must submit the form Application and Report of Abandonment of Water Well (GW-5) prior to the initiation of the abandonment procedures (Appendix 1). The Board requires this form to be filed to certify that pumping and use of ground water from that well has stopped. It also indicates that all industrial and public supply wells are sealed properly to prevent ground water contamination by other ground water of poorer quality, surface waters, and other pollutants.

Ground water quality information is collected weekly by the Piedmont Regional Office, Division of Surveillance and Field Studies. Five wells in one of the twenty-two counties in the region are selected at random and sampled each week. Most of these ground water quality samples come from wells with completion reports on record at the Piedmont Regional Office. Chemical analyses for twenty-eight ground water quality parameters are performed by the State of Virginia Consolidated Laboratory.

Ground water quality information also is acquired through the Pollution Response Program (PReP). This program responds to citizens' complaints of ground water and surface water pollution 7 days a week, 24 hours a day. Toxic and hazardous chemicals, oil, gasoline, refuse, siltation, sewage and industrial wastes are some of the pollutants that frequently endanger the quality of ground water and are reported through the PReP Program.

The central repository for all available water well and ground water quality information for Henrico County is the Headquarters Office of the State Water Control Board in Richmond. Copies of these records are on file at the Piedmont Regional Office. The information also has been recorded on computer and is made available to the interested public.

Previous Investigations

Detailed geologic reconnaissance and mapping has been recently completed for most of Henrico County by the Virginia Division of Mineral Resources (VDMR) in Charlottesville. Seven geologic quadrangle maps have been published in Geology of the Bon Air Quadrangle, Virginia, by Bruce K. Goodwin: VDMR Publication 18 (1980); Geology of the Hylas and Midlothian Quadrangles, Virginia, by Bruce K. Goodwin: VDMR RI 23 (1970); and in Geology of Studley, Yellow Tavern, Richmond and Seven Pines Quadrangles, Virginia, by Paul A. Daniels, Jr. and Emil Onuschak, VDMR, RI 38 (1974). Much information has been compiled for the remaining geologic quadrangles within the county but has not yet been published.

Hydrogeologic information is extremely limited for the entire county and was inferred from both regional reports and State Water Control Board well data. Little hydrogeologic work has been done in the Piedmont section of Henrico County. The Virginia Division of Water Resources, Groundwater of Henrico County, Virginia [Preliminary Basic Data Bulletin 36P (1971)] addresses the hydrogeology of both the Piedmont and the Coastal Plain in the county. Coastal Plain hydrogeology has been further explored by D. J. Cederstrom in Geology and Groundwater Resources of the York-James Peninsula, Virginia, 1957, and by E. A. Siudyla, T. D. Berglund and V. P. Newton, Groundwater of the Middle Peninsula, Virginia, [State Water Control Board Planning Bulletin 305 (1977)]. An excellent regional study which proved useful is Brown, P. M. et al, Structural and Stratigraphic Framework and Spatial Distribution of Permeability of the Atlantic Coastal Plain, North Carolina to New York. U.S. Geological Survey Professional Paper 796 (1972).

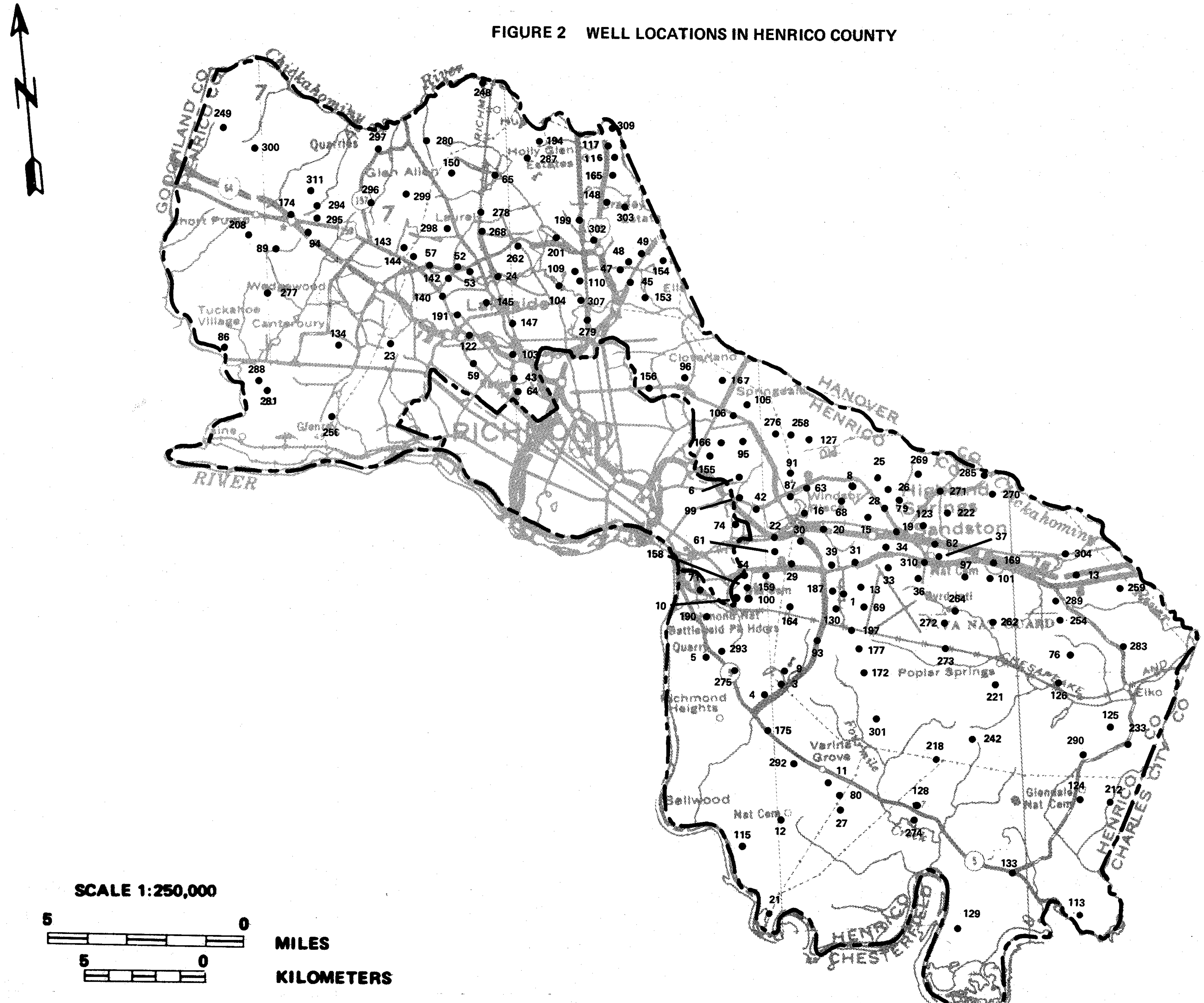
Water Well Numbering System

Each water well completion report acquired by the State Water Control Board receives a special number. The first three digits refer to the particular county or city in which the well is located. The numbers from 100 to 199 represent in alphabetical order, the counties in Virginia; and the numbers from 200 to 237 represent cities and incorporated towns. The remaining digits in the completion report number are for the particular well in the county, city or town. For example, well number 143-318 denotes the 318th recorded well in county 143 (Henrico).

All information pertaining to a particular well is given the same number. This includes water quality data, ground water pumpage and use, geophysical logs, and geologic logs. All of the wells are listed in numerical order, with most in chronological order. Both the files of the SWCB and the computer printout are based on this numbering system. When it is necessary to contact the SWCB about a particular well, it is advisable to refer to the well number, the owner, location, well depth, and the date of construction. This information will allow for more efficient assistance in retrieval of the well data.

Most wells in Henrico County for which the SWCB has information are shown in Figure 2. Detailed data on each well is included in Appendix IV.

FIGURE 2 WELL LOCATIONS IN HENRICO COUNTY



SCALE 1:250,000

5 0 MILES

5 0 KILOMETERS

Source: U. S. ARMY TOPOGRAPHIC COMMAND, VDMR,

CHAPTER II

PHYSICAL SETTING

Physiography

Henrico County contains land in both the Piedmont and Coastal Plain Physiographic Provinces of Virginia. The western portion of the county lies in the Piedmont Province. This province is generally characterized by gently rolling hills which are underlain by igneous and metamorphic rocks such as granite, gneiss and schist. The Piedmont portion also contains the Triassic Basin Subprovince. Although theories vary on the former extent and sequence of formation of these basins, it is generally agreed that they take the form of gently folded and faulted grabens and half grabens containing conglomerate, shale, sandstone, and coal measures deposited in shallow basins during the Triassic Period, 235 to 195 million years before present (MYBP). The Richmond Triassic Basin outcrops at the extreme western edge of Henrico County. Elevations above mean sea level (msl) in the Piedmont portion of Henrico County range from about 30 meters (100 feet) in drainageways near the Fall Zone to slightly above 91 meters (300 feet) in the west-central part of the county. (Fig. 3)

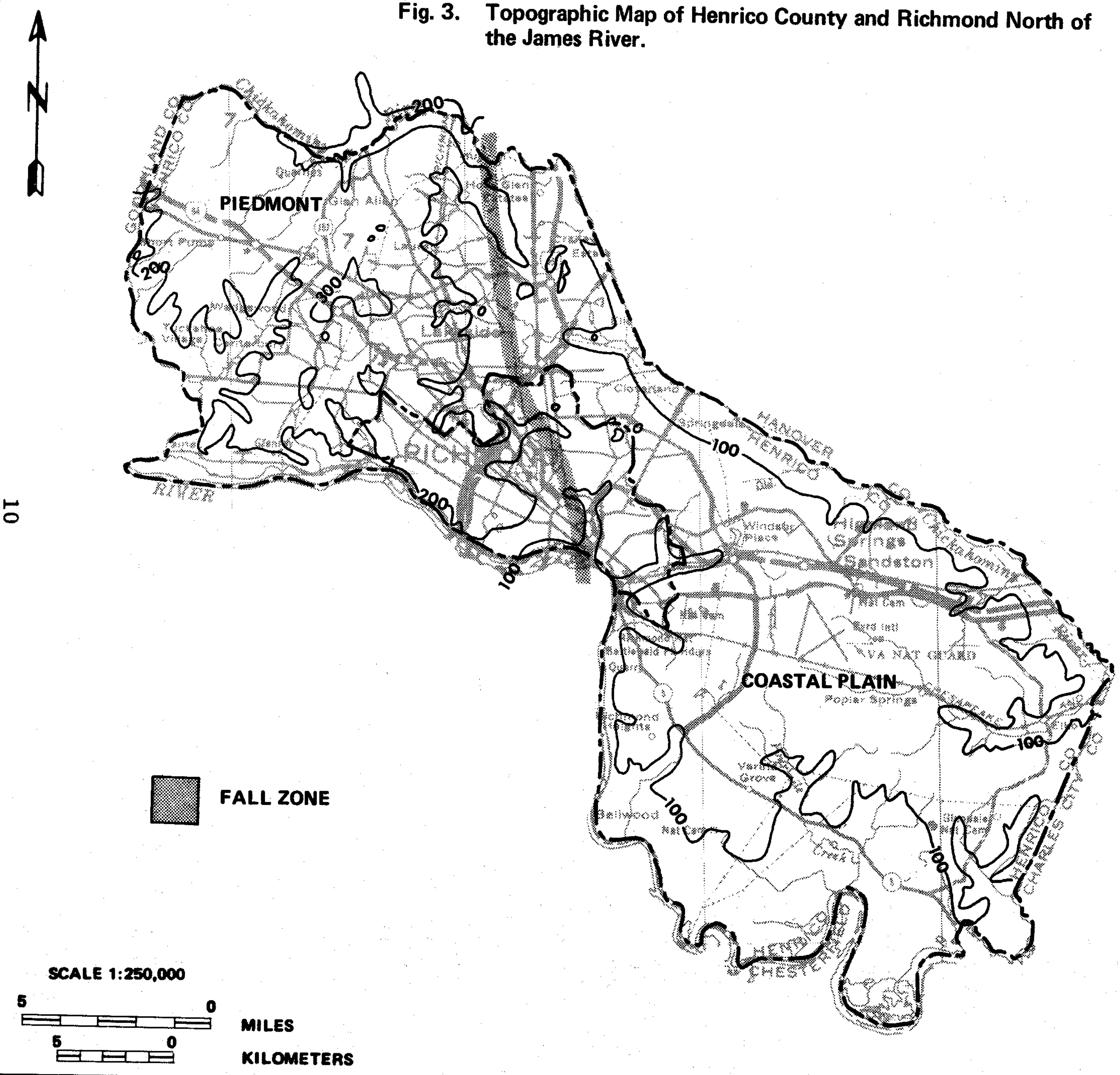
The eastern portion of the county lies in the Coastal Plain Province. Coastal Plain geology is characterized by beds of unconsolidated sediments such as clay, sand and gravel that increase in thickness as they gently dip to the east. To the west these beds generally thin and terminate at the Fall Zone. The nearly-flat topography and unconsolidated sediments of the Coastal Plain have caused the streams and rivers in the area to meander. Elevations above mean sea level (msl) in this area range from 3 meters (10 feet) in the easternmost drainageways to 45 meters (150 feet) near the Piedmont rock outcrops at the Fall Zone. (Figure 3)

The Piedmont and Coastal Plain Provinces are separated by the Fall Zone, which extends in a north-south direction through the central portion of the study area. The Fall Zone is the area along the eastern margin of the Piedmont where stream gradients steepen as the streams pass from the resistant crystalline rocks of the Piedmont to the easily-eroded unconsolidated sediments of the Coastal Plain. East of the Fall Zone the eastward dipping crystalline basement rocks are overlain by an increasing thickness of Coastal Plain sediments. (Figure 4)

Land Use

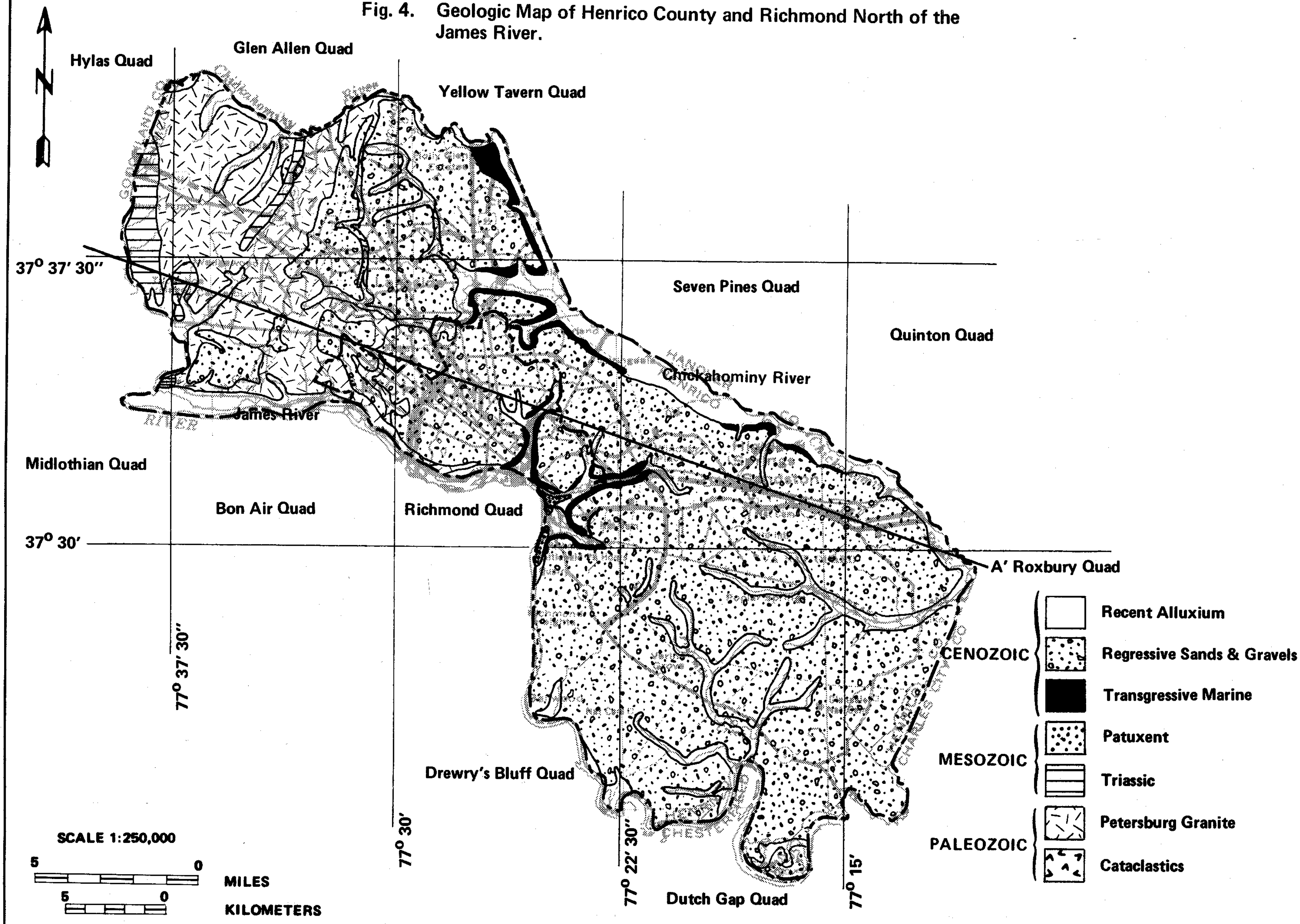
For planning purposes, land use areas have been divided into active and passive categories. Of the active categories, it was estimated in 1974 that single family dwellings accounted for the greatest percentage of actively used land (13.3% of the total land area). Moreover, this

Fig. 3. Topographic Map of Henrico County and Richmond North of the James River.



SOURCE:U. S. ARMY TOPOGRAPHIC COMMAND, VDMR,

Fig. 4. Geologic Map of Henrico County and Richmond North of the James River.



SOURCE: Goodwin 1970, Daniels & Onuschak 1974, Goodwin 1980, VDMR

Rev. 6/80

category showed the highest rate of increase followed by the multi-family category. This fact, when coupled with figures predicting continued population growth, indicates an increasing demand will be placed on ground water resources as additional water supplies are needed to service new homes. In 1974 the other "active" uses ranked as follows: public, heavy industrial, semi-public, commercial service, multi-family residential, light industrial, and office. Of the 38,042 hectares (94,000 acres) zoned for agricultural use, only about 10% was actually in use.

Passive land use includes that 12% of the county which can only be developed for recreation and that 64% of the land not considered prime vacant. Development of the prime vacant land will place future demands on water supplies.

Surface Hydrology

Henrico County is located in the James River Basin. Drainage is eastward toward the Chesapeake Bay, with the James and the Chickahominy Rivers draining the county in equal proportions. Some of the major streams in the county include: Upham Brook, North Run, Tuckahoe Creek, Whiteoak Swamp Creek, Four Mile Creek, Deep Run, Cornelius Creek, Brook Run and Rocky Branch.

Climate and Soils

The climate is temperate in Henrico County with cold, but not severe, winters and moderately warm summers. The usual range for winter temperatures is from -2°C to 10°C (29°F to 50°F). The usual range for summer temperatures is from 18°C to 31°C (65°F to 87°F). Precipitation averages 1.11 meters (44.2 inches) per year. Droughts and flooding are fairly common in Henrico County, with the major floods being caused by hurricane activity. Temperature and precipitation data are given in Table 1.

The soils of Henrico County have been described in a publication entitled Soil Survey of Henrico County, Virginia (1975) by the United States Department of Agriculture Soil Conservation Service, in cooperation with Virginia Polytechnic Institute and State University. The soil survey identified one hundred eleven soil types in the county. (Figure 5) Generally, soils are derived from weathering of the underlying parent material. Therefore, the soils overlying the crystalline Piedmont rocks differ markedly from those found in the Coastal Plain portion of the county.

TABLE 1

TEMPERATURE AND PRECIPITATION DATA

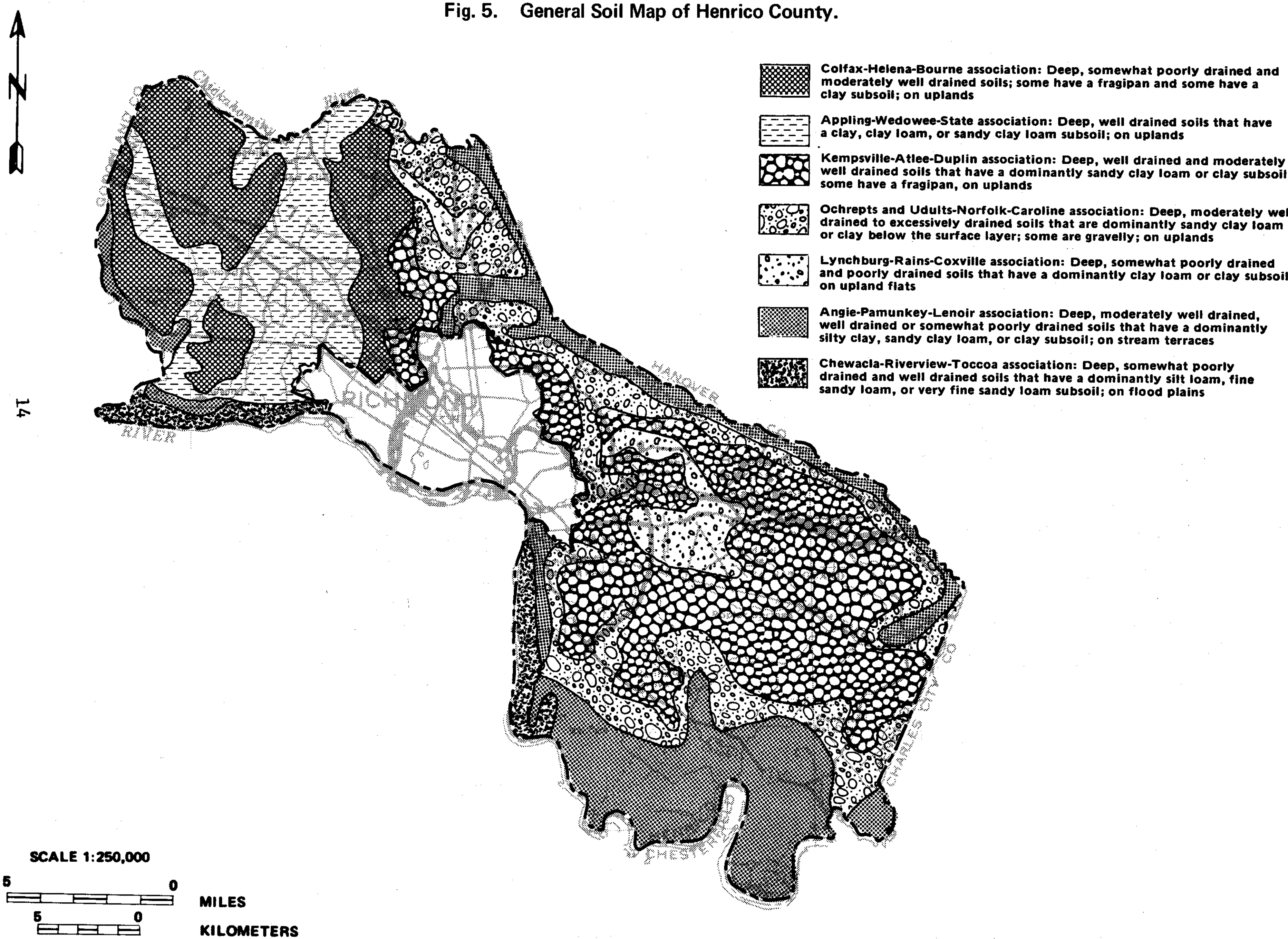
[Data from records at Byrd Field, Richmond, Virginia]

Month	TEMPERATURE °C (°F)				PRECIPITATION CM (IN)				
	Average daily maximum °C (°F)	Average daily minimum °C (°F)	Two years in 10 will have at least 4 days with--		Average total CM (IN)	One year in 10 will have--		Days with snow cover 2.54cm (1 inch) or more in depth	Average depth of snow on days with snow cover
			Maximum temperature equal to or higher than--	Minimum temperature equal to or lower than--		Less than-- CM (IN)	More than-- CM (IN)		
January----	8.9 (48)	-1.6 (29)	18.9 (66)	-10.9 (13)	8.9 (3.5)	3.0 (1.2)	13.5 (5.3)	4	12.7 (5)
February---	10.5 (51)	-1.6 (29)	19.5 (67)	-8.9 (16)	7.4 (2.9)	3.6 (1.4)	11.2 (4.4)	2	10.2 (4)
March------	15.0 (59)	2.2 (36)	22.8 (73)	-5.0 (23)	8.6 (3.4)	4.6 (1.8)	12.7 (5.0)	2	12.7 (5)
April------	21.1 (70)	7.8 (46)	30.0 (86)	0.0 (32)	8.1 (3.2)	4.3 (1.7)	13.2 (5.2)	*	2.5 (1)
May--------	26.1 (79)	12.8 (55)	31.1 (88)	6.1 (43)	9.4 (3.7)	3.6 (1.4)	18.5 (7.3)	-----	--------
June-------	30.6 (87)	17.2 (63)	33.9 (93)	11.7 (53)	9.7 (3.8)	3.0 (1.2)	20.8 (8.2)	-----	--------
July-------	31.7 (89)	19.5 (67)	35.0 (95)	15.6 (60)	14.2 (5.6)	5.6 (2.2)	25.9 (10.2)	-----	--------
August-----	30 (86)	18.3 (65)	34.5 (94)	13.3 (56)	14.0 (5.5)	4.6 (1.8)	23.4 (9.2)	-----	--------
September--	27.8 (82)	15.0 (59)	32.8 (91)	8.3 (47)	9.1 (3.6)	2.0 (0.8)	19.1 (7.5)	-----	--------
October----	21.7 (71)	8.3 (47)	28.3 (83)	2.8 (37)	7.6 (3.0)	2.3 (0.9)	13.5 (5.3)	-----	--------
November---	15.6 (60)	2.9 (37)	28.3 (83)	-3.3 (26)	7.6 (3.0)	2.0 (0.8)	13.5 (5.3)	*	5.1 (2)
December---	10.0 (50)	-1.1 (30)	18.9 (66)	-8.9 (16)	7.6 (3.0)	3.3 (1.3)	11.9 (4.7)	2	10.2 (4)
Year-----	20.7 (69)	8.3 (47)	37.2 (99)**	-13.3 (8)***	112.3 (44.2)	80.0 (31.5)	135.9 (53.5)	10	10.2 (4)

* Less than one-half day.
** Average annual highest temperature.
***Average annual lowest temperature.

Source: Soil Survey of Henrico County, USDA, 1975

Fig. 5. General Soil Map of Henrico County.



SOURCE: U.S. Dept. of Agriculture — Soil Conservation Service

CHAPTER III

GEOLOGY

Regional Geologic Setting

Henrico County encompasses portions of both the Piedmont and the Coastal Plain Physiographic Provinces. The Fall Zone marks the interface between the outcrop area of the eroding crystalline rocks to the west (Piedmont) and the area where the crystalline rocks are overlain by relatively flat-lying marine and near-shore deposits to the east (Coastal Plain).

These two provinces, as well as three other physiographic provinces to the west (Blue Ridge, Valley and Ridge, and Appalachian Plateau), are present along the eastern United States from New York to Alabama. The present arrangement of the rocks in the Piedmont has been attributed to a geologic event known as the Appalachian Orogenic Revolution (Silurian to Permian Periods, 435 to 285 MYBP)(Table II). During this mountain building event the already metamorphosed sediments which had been deposited in what is now the Piedmont were further altered (Bobyarchick and Glover, 1979).

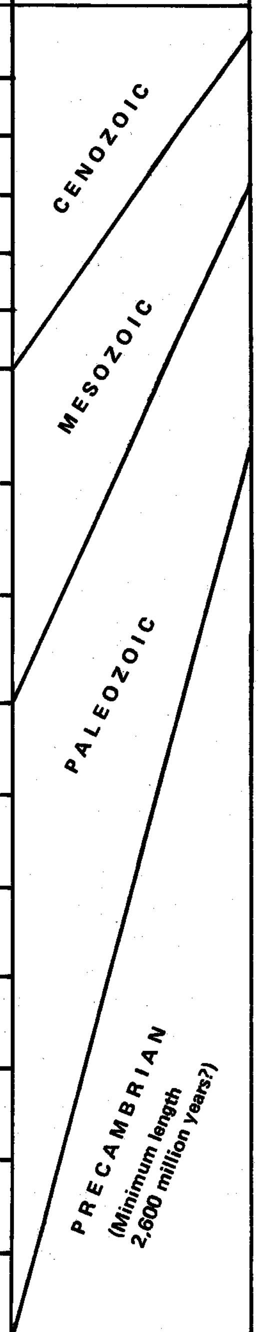
The Appalachian Orogenic Revolution may be explained by the theory of plate tectonics. This theory, based on seismic, geologic, geomagnetic, paleontologic, heat flow and geographic data, proposes that continents are composed of a relatively rigid material which floats upon a denser but more fluid material at depth. Movement of this denser more fluid material through long periods of time has caused continental movement. Oceans have been created by continents migrating away from each other. Mountains have been formed by continental collisions.

It has been proposed that at the beginning of the Paleozoic Era (570 MYBP) the Atlantic Ocean began to open up as the North American Plate and the European Plate migrated away from each other. During this period sediments were deposited along the eastern margin of the North American Plate. By the end of the Ordovician Period (435 MYBP) the Atlantic began to close, a process which continued through the Devonian Period (405 to 350 MYBP). The compressive forces generated when the North American and European Plates came together folded the accumulated sediments along the continental shelf and rise. This mountain building was accompanied by volcanism and magmatic intrusion (Press and Siever, 1974). The compressive forces continued during the Late Paleozoic Era while the continents remained together. It is thought that the Piedmont rocks to the west of the area of this study reached their present state of metamorphism at that time (Bobyarchick and Glover, 1979). These western Piedmont rocks are believed to represent either the cores of mountains long since eroded (Press and Siever, 1974) or the remnants of a "microcontinent" which was thrust westward from a point in the Atlantic during the Early Paleozoic Era (Harris and Bayer, 1979).

Table 2. Scale of Geologic Time

Subdivisions of Geologic Time				Apparent Ages (millions of years before the present)
Eras	Periods	Epochs	Ages	
CENOZOIC	Quaternary	(Recent) Pleistocene		
				2
	Tertiary	Pliocene		
				5.2
		Miocene		
				24
		Oligocene		
				37
		Eocene		
				54
		Paleocene		
				65
MESOZOIC	Cretaceous			
				135
	Jurassic			
				195
	Triassic			
				235
PALEOZOIC	Permian			
				285
	Pennsylvanian			
				325
	Mississippian			
				350
	Devonian			
				405
	Silurian			
				435
	Ordovician			
				500
	Cambrian			
				570
PRECAMBRIAN (No worldwide subdivisions)				

Relative Lengths of Major Time Divisions, to True Scale



SOURCE: VDMR

TABLE III

ROCK UNITS AND THEIR CHARACTERISTICS

AGE	Rock Unit Name	DISTINGUISHING CHARACTERISTICS	SUITABILITY AS AN AQUIFER
Quaternary	Recent Alluvium (RA)	Organic and poorly sorted river deposits ranging from clay to gravel	Susceptible to contamination
	Regressive (Reg)	Coarse sand and gravels	Good for shallow wells, vulnerable to seasonal fluctuations in water table
Tertiary			
	Yorktown (Ty) Eastover (Te) Choptank (Tch) Nanjemoy (Tn) Aquia (Ta)	Transgressive Marine drab grayish-green, glauconite clayey silt and quartz sand, fossiliferous	Inferior to underlying and overlying beds due to high clay content
Cretaceous	Patuxent (kptx)	Fine gravel, coarse sand with a high feldspar content, silty to sandy clay	Extremely productive aquifer
Triassic (TRN)	Sandstone	Fine to coarse grained, arkosic containing muscovite, found interbedded with shales	Variable permeability
	Shale	Gray to reddish brown when fresh, red when weathered, "red beds"	Low permeability except when fractured
	Conglomerate	Interbedded with medium to coarse grained sandstone, cobbles and boulders mostly of granite	Variable permeability
	Coal	Found interbedded with sandstone and shale fossils of plant stems and leaves found	Not known to be a good aquifer most permeable when fractured (Freeze & Cherry, p. 157)
	Diabase	Fine to medium grained, dense dark-gray diabase	Highest well yields in deep saprolite or fractured areas
Paleozoic	Petersburg granite (PZPB)	Phase 1: gray to pink medium grained granite Phase 2: blue, fine grained granite Phase 3: porphyritic granite	Many shallow wells in overlying saprolite and jointed areas
	Cataclastic rocks	Mostly gray green fine grained dense metarhyolites, gneisses and phyllites	Variable yield depending on depth of saprolite and jointing

The rocks in the Piedmont section of Henrico County are now thought to date from the Late Paleozoic (Bobyarchick and Glover, 1979). It is now believed that the continents began to drift apart in the Late Paleozoic or Early Mesozoic Era. As the compressive forces were released, the brittle rocks of the North American continent became cracked. During Triassic and Jurassic time, block faulting resulted creating basins throughout the Eastern United States (Bobyarchick and Glover, 1979). Material eroded from the Piedmont rocks has been deposited in the east among the gently sloping sedimentary formations of the Coastal Plain.

In view of the many differences between the geology of the Piedmont and Coastal Plain provinces and the direct effect these differences have on ground water quality and production, the provinces are discussed separately in this report.

Piedmont Geology

The Piedmont section of Henrico County is made up of three distinct rock units that were formed during Early Paleozoic to Triassic time (Bobyarchick and Glover, 1979). These rock units are the cataclastic rocks, the Petersburg granite, and the Triassic rocks.

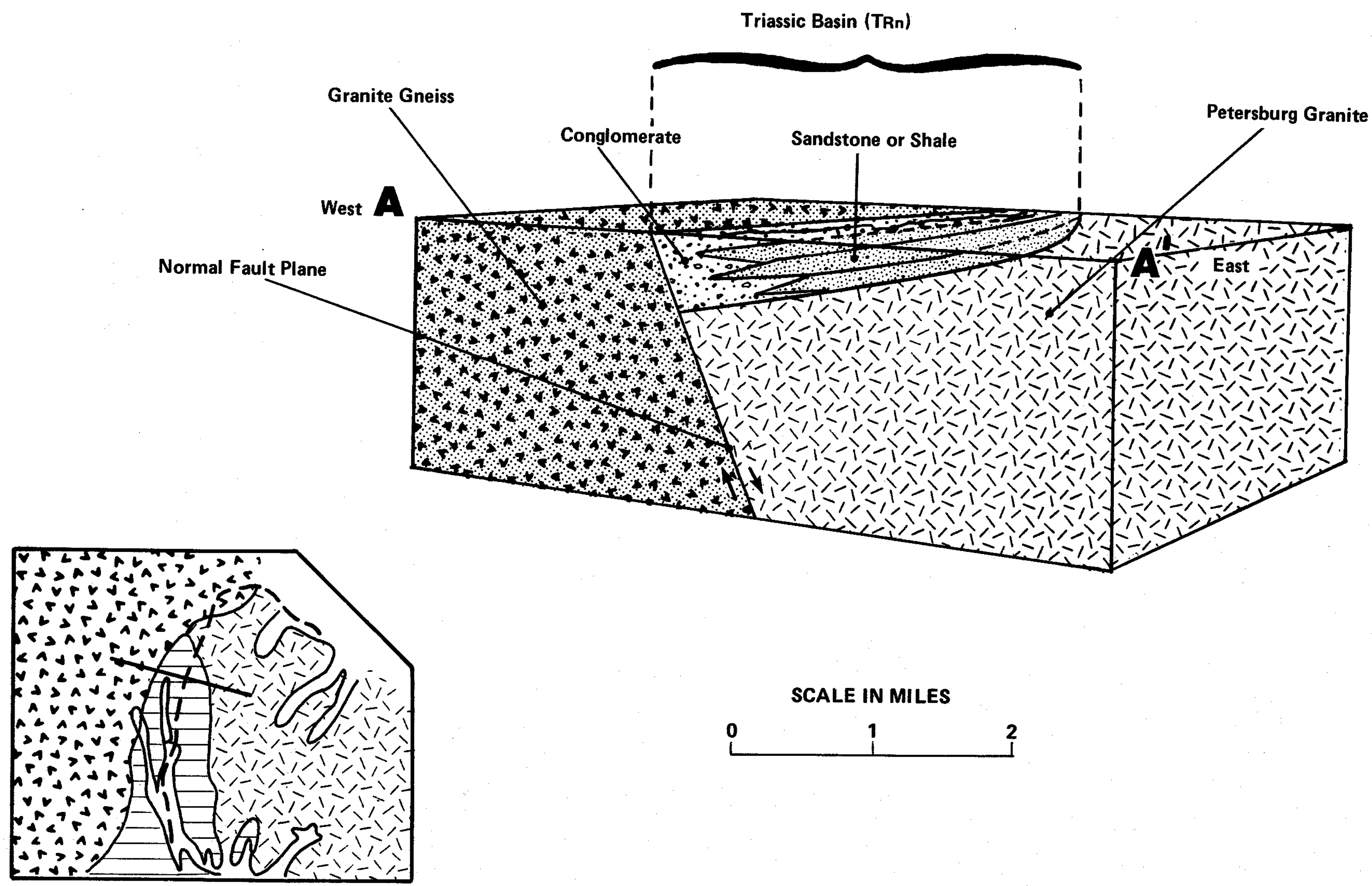
The extreme northwest corner of the county is underlain by cataclastic rocks. Cataclastic rocks are those whose structure shows the effects of severe mechanical stress. Goodwin (1970) describes these rocks as mostly gray-green, fine-grained, dense metarhyolites, gneisses and phyllites. According to Goodwin the cataclastics are distinguished from adjacent rocks by their closely-spaced jointing. The age of these rocks has not been determined. Goodwin believes them to be younger than the Precambrian gneisses to the west. The cataclastics have been intruded by diabase dikes which also have intruded Late Triassic age rocks to the east.

The Petersburg granite is the oldest unit and has been described as a batholithic intrusion dating from the Late Paleozoic (Conley, 1978) the period of time when the then linked North American and European continents began to separate. Three phases are present in the Petersburg granite: a gray to pink medium-grained granite; a blue, relatively fine-grained granite, and a porphyritic granite.

Triassic age rocks are a conspicuous feature of the Piedmont section of Virginia because they are found in the midst of older igneous and metamorphic rocks. These rocks are found in what have become known as Triassic basins (Figure 6). Palynological evidence has been interpreted to affix a Late Triassic to Jurassic date for the formation and filling of these basins.

According to Goodwin (1970), there are differing theories concerning the origin and previous extent of the basins. While the initial block faulting may be explained by a release in pressure (tensile stress)

Fig. 6. Schematic Diagram Showing a Typical Triassic Basin Cross-Section.



SOURCE: STATE WATER CONTROL BOARD – PRO

accompanying separation or splitting of the continents, later folding of the Triassic-Jurassic sediments and movement along the border faults has yet to be explained fully.

Four different types of rock have been identified in the Richmond Triassic basin: shale, arkosic sandstone, conglomerate, and coal measures (Goodwin, 1970). Interbedded Triassic sandstones and shales are found at the surface of the western margin of the county. The beds of shale appear gray to brownish-red when fresh, but when exposed to weathering they become more reddish; thus they are called "red beds". These characteristic "red beds" are found to the east under the overlying Coastal Plain deposits, showing that Triassic basins formed there also. Triassic conglomerate occurs on the eastern and western sides of the Richmond basin (Goodwin, 1970). Triassic conglomerate has been mapped in the area between Route 250 and Kain Road between outcrops of interbedded sandstone and shale and outcrops of the Petersburg granite. As Goodwin describes it, the conglomerate is interbedded with a medium-to-coarse-grained sandstone. The conglomerate contains cobbles and boulders composed predominantly of granite. In the southern part of the western margin of the county, between the Petersburg granite and the interbedded sandstone and shale, there is a north-to-south-trending band of coal. This band runs on either side of Gayton Road and continues south into Chesterfield County. Another section of coal measures in the Richmond basin straddles the portion of Gayton Road which runs east to west. About 3.6 miles east of the coal measures is the Deep Run Basin, a northeast trending basin comprised entirely of coal measures straddling U.S. Rt. 250. The coal measures consist of coal interbedded with arkosic sandstone and shale. The youngest rocks in the Triassic basins are the diabase dikes which intrude all of the Triassic sedimentary rocks.

The Piedmont rocks have been and still remain subject to intensive weathering processes. The in-place end product of the disintegration of the Piedmont crystalline and consolidated Triassic rocks is referred to as saprolite. Except for an occasional rock outcrop, saprolite covers all the Piedmont hard rock. Saprolite varies in depth, and its thickness and mineral composition have a direct effect on the quality and quantity of shallow sources of ground water.

Coastal Plain Geology

General Stratigraphy

The Coastal Plain area of Henrico County is composed of a sequence of marine and non-marine sedimentary formations. These formations are composed of clay, silt, sand and gravel which were deposited on the eastward-sloping, Piedmont-like, "basement complex" rocks. The Coastal Plain units dip and thicken to the east.

The oldest of these units is the Patuxent Formation. It is believed to date from a time of active tectonism in the Early Cretaceous Period. During that time deposits from the Piedmont (west) were eroded and transported to the east and deposited in a series of deltaic lobes which were filling the near-shore marine bays (Daniels and Onuschak, 1974). This hypothesis is postulated in part from the nature of the sediments found. They include fine gravel, coarse sand with a high feldspar content, and silty to sandy clay. The coarse materials are indicative of a high-energy, near-shore, depositional environment. The coarse nature of the sediments makes the Patuxent Formation a highly productive aquifer wherever it is found in the Coastal Plain.

The Patuxent Formation was subsequently covered by a number of formations which were deposited in a cyclic pattern. Each of these units is thought to represent a separate period of advance (transgression) and retreat (regression) of the sea. Such a cycle contains deposits of marine, near-shore, estuarine and fluvial environments. The oldest of these units, the Aquia Formation was deposited during the Paleocene Epoch. Above the Aquia is the Nanjemoy Formation of Eocene age. The Marlboro Clay Member of the Nanjemoy rests directly on top of the Aquia. The next unit, known locally as the "Miocene marl", includes the Choptank and Eastover Formations (Gene Rader, VDMR, personal communication, 1981). In the far eastern portion of the county the marine phase of the Yorktown Formation of Early Pliocene age has been identified. The fluvial phase of the Yorktown has been identified as far west as I-95 (Gene Rader, VDMR, personal communication, 1981).

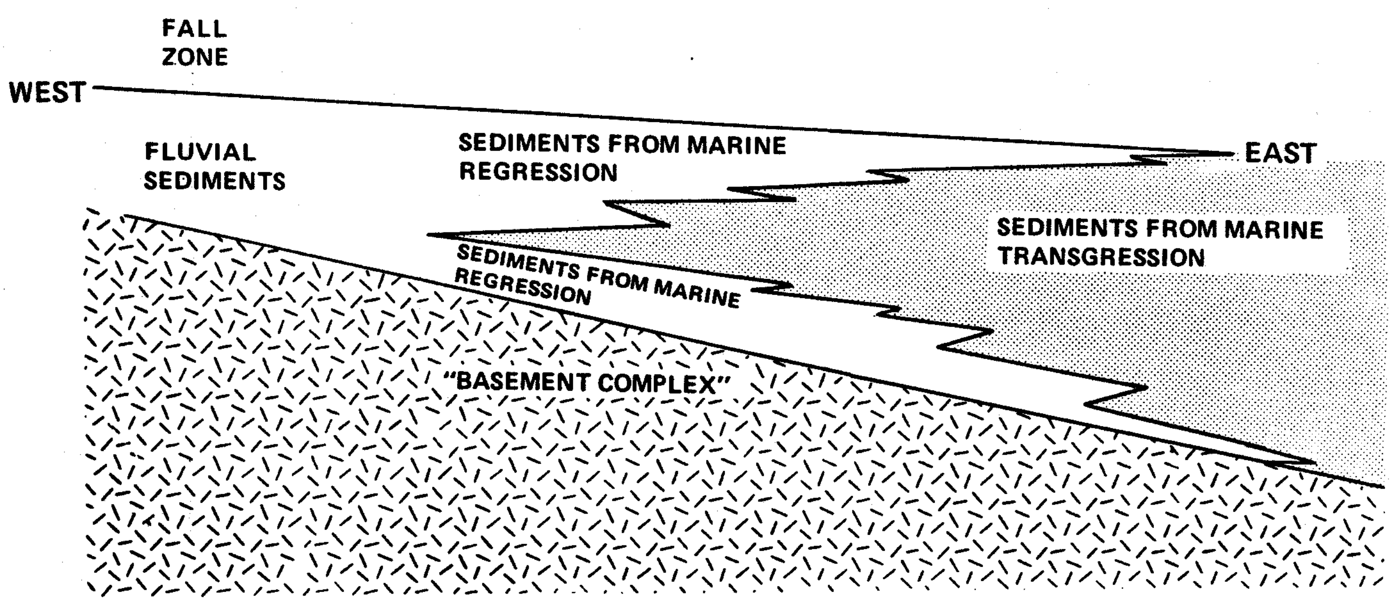


Fig. 7. West-East, Generalized, Cross-Section, Depicting Marine Regressive and Transgressive Deposition in the Costal Plain Portion of Henrico County.

Tertiary and Quaternary age units make up the remaining bulk of the surface geology of the Coastal Plain. At the present time work is being done to differentiate and correlate the fluvial units in them with their marine and estuarine equivalents. The coarse sands and gravels represent the regressive portion of the formations. The latest unit deposited is the recent alluvium found in the stream valleys and flood plains of the James and Chickahominy Rivers.

Coastal Plain Tectonism

Evidence such as the distinct southward turn of Virginia's eastern rivers has suggested to geologists the presence of fault systems in the Coastal Plain. Work is now in progress to relate known fault exposures to other data in order to delineate these fault systems. The presence of an exposed fault on the south side of the James River at Drewry's Bluff suggests that a north-south-trending fault system may extend north into Henrico County. Similar faults observed in other areas are high-angle reverse faults affecting formations dating from the Cretaceous Period to the Miocene Epoch. The fact that the older formations are more deformed than the younger formations suggests that the deformation has been a long-term process, with movement continuing through much of the Tertiary Period (65 to 2 MYBP).

CHAPTER IV

HYDROGEOLOGY

General

Hydrogeology is defined as the study of ground water and its relationships with the surrounding subsurface geology. Ground water represents one of the stages in the movement of water through the hydrologic cycle (Figure 9). The ground water portion of this cycle is dependent upon the amount and frequency of precipitation received in a given area and, perhaps more specifically, the amount of the precipitation which infiltrates into the subsurface. It is this portion of the hydrologic cycle, precipitation and infiltration, which is responsible for eventually recharging all ground water resources. The rate of infiltration and the storage capacities of the rock formations are the keys to the quantity of ground water available as a resource in any given area.

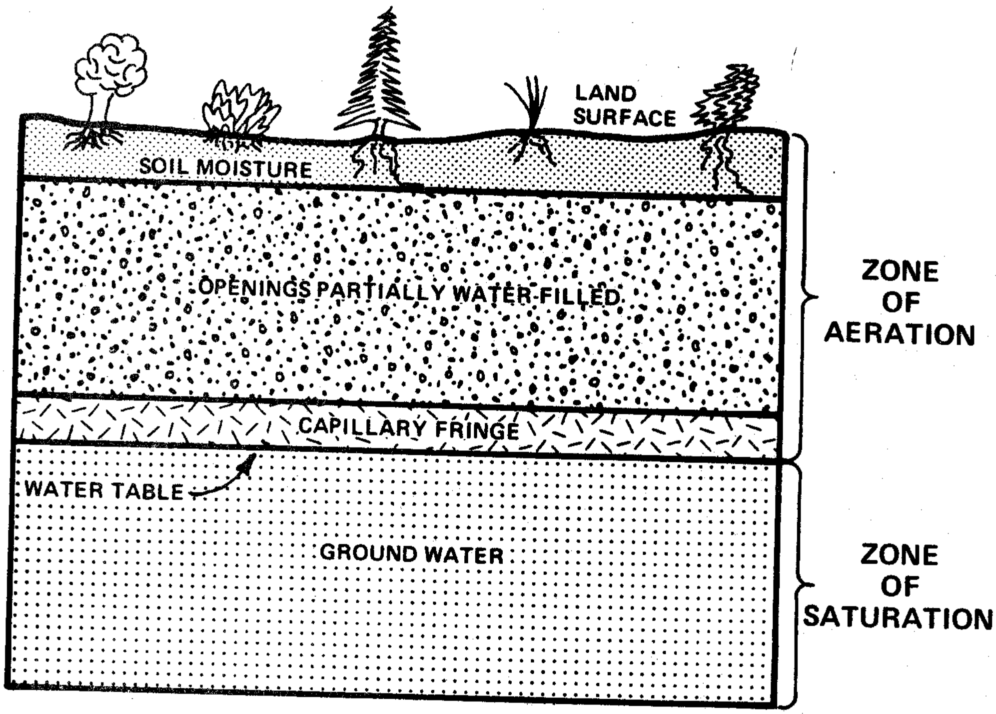
Precipitation percolates into the subsurface through pores and openings in the soil cover and rock. Prior to reaching the ground water table the water passes through the Zone of Aeration. The Zone of Aeration is actually comprised of three separate zones which grade into each other. The uppermost of these zones is the soil-water zone. Here water is held in the fine grained soil material by forces of molecular attraction and plant roots. The next lower zone is the intermediate zone where the pore spaces are partially filled with water. Beneath the intermediate zone is the capillary fringe where water is drawn upward above the water table and held in place by capillary action. Below the capillary fringe is the Zone of Saturation, an area where all interconnected pores are filled with water. The Zone of Saturation is the ground water reservoir and the top of this zone is the ground water table. (Figures 8a and 8b)

Soil conditions, vegetation, soil chemistry, topography, rock types, and geologic structure all influence the quantity and quality of the ground water. Of these influencing factors, topography, rock type, and geologic structure are the major factors controlling the recharge, storage, quality, and quantity of a ground water resource. Although these factors will be discussed in detail below, it should be stressed that many of the parameters which affect ground water are inter-related in very complex ways. A complete discussion of these interrelationships is beyond the scope of this report.

Topography

The present topography in the Henrico County area has evolved primarily due to differential weathering of the existing rock and sediments. Topographically-high areas generally are underlain by well-consolidated, unfractured bedrock or areas of impermeable

Fig. 8a. Subsurface Water Zones.

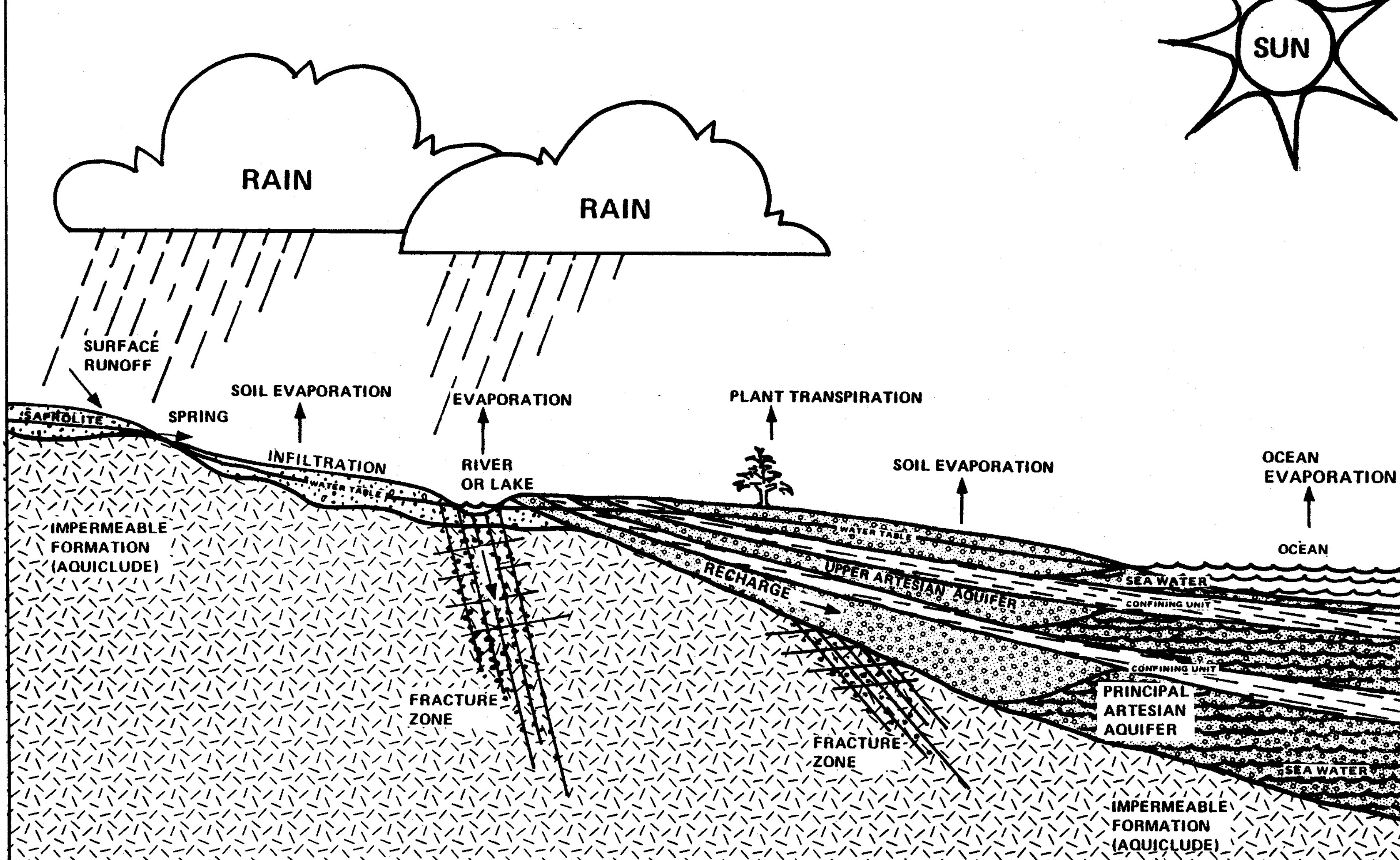


Source: Virginia State Water Control Board

		Ground Level
Zone of Aeration	(indefinite depth)	Discontinuous moisture zone Moisture films not connected
Capillary Fringe Zone	(indefinite depth)	Soil partially saturated, moisture continuous
Zone of Saturation	Water Table Δ	Soil saturated, moisture continuous

Figure 8b Soil Moisture Distribution Source: SWCB-NRO

Fig. 9. Hydrologic Cycle.



SOURCE: STATE WATER CONTROL BOARD – PRO

clays. These high areas may be contrasted to areas dominated by fractured, jointed, or unconsolidated rocks and sediments which have become the topographical lows due to accelerated downward erosion. Many of the naturally-flowing streams and springs that subsequently occupy these topographically-low areas are also the surface expression of the ground water table. They represent an intersection of the ground water table with the land surface.

The infiltration rate is greatly dependent upon topographic slope and rock structure. Steeply-sloping land areas cause rapid runoff, allowing very little time for infiltration to occur. Conversely, gently-sloping to flat areas allow longer water retention times. The geologic structure has a similar impact on runoff and infiltration. If the underlying rock is free of joints, fractures and pore spaces, water will not percolate into it but will run off or stay at the soil-rock interface. A high-relief soil-rock interface will contribute to high relief surface topography. The resultant slopes will encourage runoff of precipitation by causing short water retention times. Excessive runoff leads to erosion of the soil zone This further inhibits infiltration by removing the soil as a water storage medium above bedrock.

Water that infiltrates into the subsurface eventually recharges the ground water reservoir. The upper surface of this reservoir is called the ground water table and it usually parallels the surface topography (Figure 9).

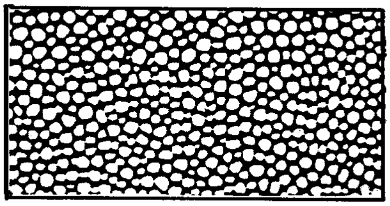
Rock

As used in this report, the term "rock" and "rock unit" will mean both consolidated and unconsolidated materials. Each rock or rock unit has specific external and internal physical and chemical characteristics which greatly affect the quality and quantity of the ground water resource. The most important physical characteristics of a rock which affect its water-yielding capabilities are its porosity and permeability. Porosity is defined as the volume of a rock unit which is not occupied by solid material. It directly relates to the ground water storage capacity of the unit. Permeability is defined as the capacity of the rock unit to allow ground water movement. It is a measure of the rock's ability to transmit its stored ground water. Both the porosity and permeability of any rock unit are dependent upon the size and orientation of its mineral grains and the presence of voids, fractures and joints. (Figure 10) A highly permeable and porous rock (i.e., sand) is ideal for ground water infiltration, storage, and transmission. In contrast, a rock unit such as clay can possess a high degree of porosity, but have a low permeability and, therefore, be a very poor ground water transmitter. The terms aquifer, aquitard, and aquiclude describe the overall ground water transmission characteristics (permeability) of a geologic formation and are directly associated with the rock type. An aquifer is described as a rock unit which allows the transmission and rapid well-recovery of ground water.

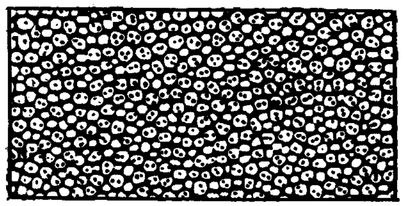
Fig. 10. Diagramatic Representations Showing Examples of Porosity and Permeability.

EXAMPLES OF POROSITY –

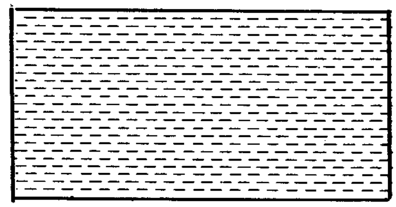
– Porosity is the amount of pore space, or volume of a formation which is not occupied by solid material.



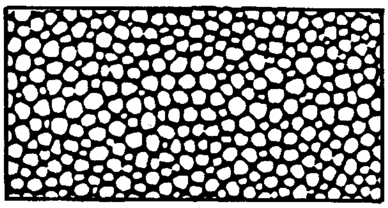
– Well-Sorted, Medium Size Sediment (High Porosity)



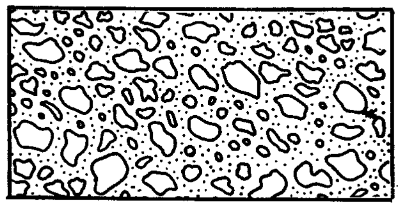
– Well-Sorted Medium Size Sediment with Porous Grains (Very High Porosity)



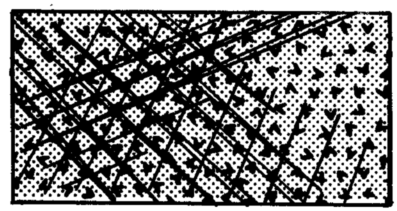
– Clay (High Porosity)



– Well-Sorted Gravel - (Very High Porosity)



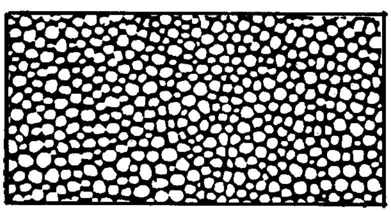
– Poorly Sorted Sediment (Low Porosity)
– If Intergranular Space is Cemented - (Very Low Porosity)



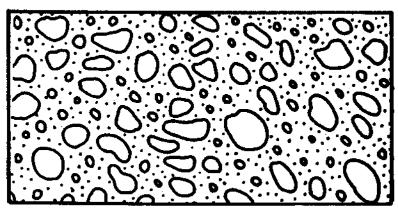
Piedmont Type Bedrock
– Cavities Developed Along Fractures and Joints (Very High Porosity)
– Interconnected Fractures (High Permeability)

EXAMPLES OF PERMEABILITY

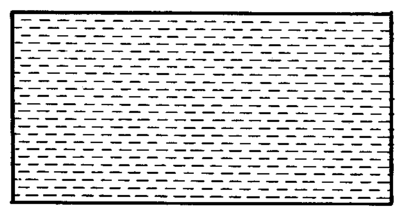
– Permeability is the capacity of a porous medium to transmit water.



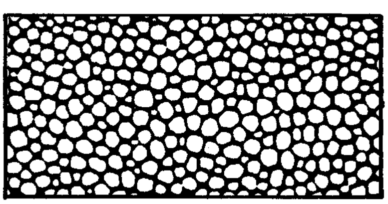
– Well-Sorted, Medium Size Sediment (High Permeability)



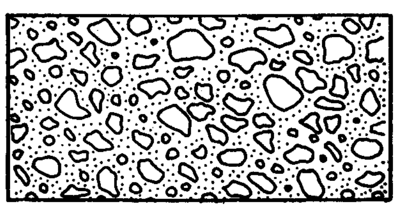
– Poorly Sorted Sediment (High Permeability – Lower than Well Sorted, Coarse Sediment)



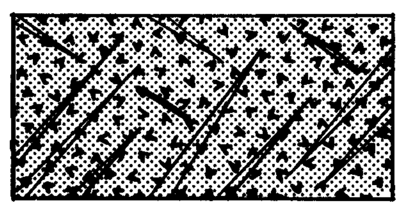
– Clay (Very Low Permeability)



– Well-Sorted, Gravel (Highest Permeability)



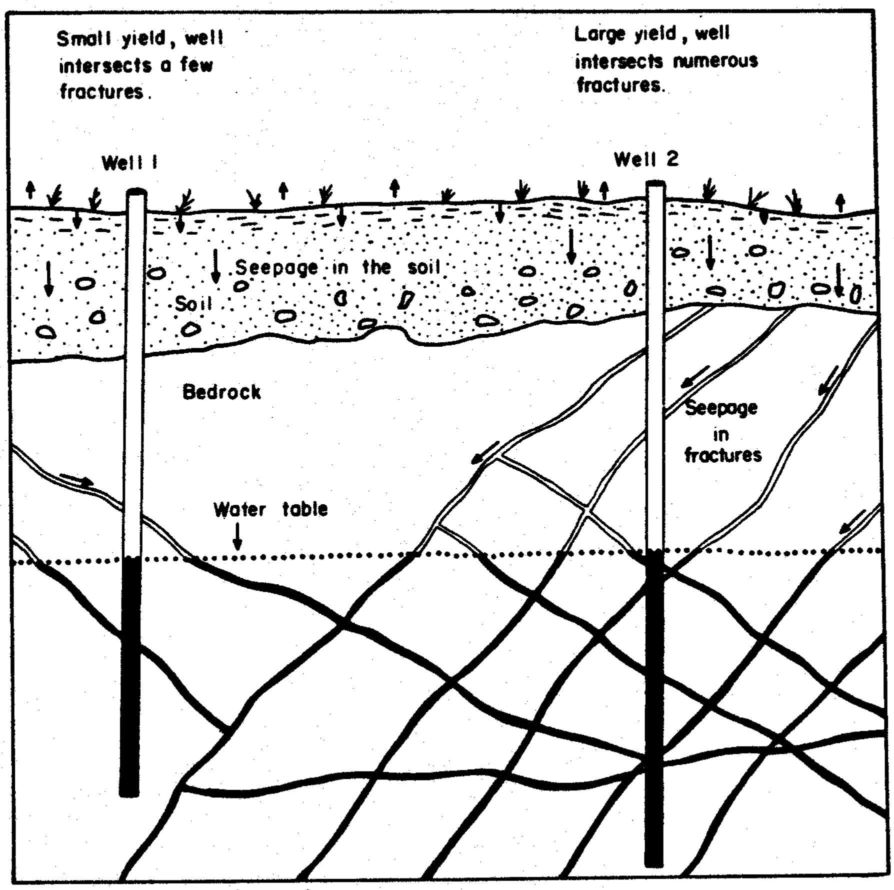
– Poorly-Sorted Sediment, Cemented Inter-Granular Spaces (Very Low Permeability)



Piedmont Type Bedrock
– Non-Connecting Fractures and Joints (Very Low Permeability)

SOURCE: STATE WATER CONTROL BOARD -- PRO

Fig. 11. Fractures in Bedrock Formations Affect Well Yield.



Source: Newport (1971)

The chemical composition of the rock unit affects or determines the water quality. Various chemical constituents of the rock unit are dissolved in the ground water as it moves through the unit. Infiltration rates and the amount of time the water remains in intimate association with the rock are important factors in determining ground water quality.

Geologic Structure

The geologic structure of an area refers to the relative positions of rock units or formations with respect to such characteristics as thickness, extent, and regional dipping or warping. Within each rock unit the term refers to the orientation of the rocks and is characterized by small scale folding, jointing, and faulting. Such structural features can hinder or hasten ground water recharge, movement, and storage. (Figure 11)

The presence of faults, fractures and joints can greatly enhance the porosity of a geologic unit. If the joints and fractures are interconnected, water can percolate into the unit more easily and move through the unit with greater ease thereafter. A high angle of dip may also increase the infiltration rate (recharge rate).

Piedmont Hydrogeology

The Piedmont section of Henrico County is characterized by consolidated rock formations which are overlain by a relatively thin saprolite "soil" cover. The hydrogeologic characteristics of these consolidated rocks must be evaluated on a site-by-site basis. Of the consolidated rocks, the igneous and metamorphic units found in the Piedmont section generally are impermeable but the effects of weathering, jointing, and faulting have created spaces for ground water to accumulate within these units. It is important to note that joints and fractures generally decrease in size and number with increasing depth. Drilling a well in the Piedmont deeper than 91 to 122 meters (300 to 400 feet) is usually inadvisable unless site specific studies have shown that yields indeed increase with depth.

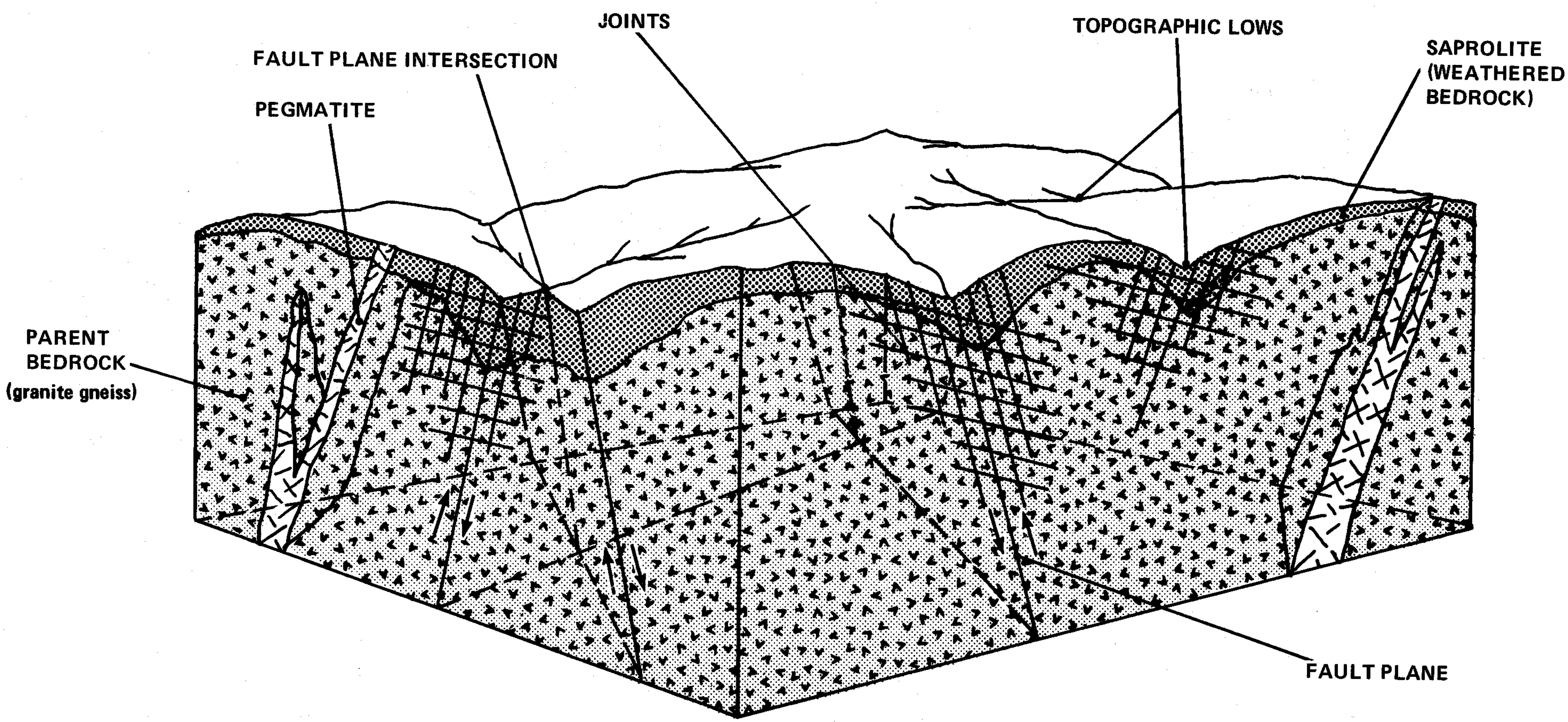
Paleozoic Rocks (330 MYBP)

Cataclastic rocks cover only a small portion of the northwest corner of the county, approximately 88 hectares (218 acres). They are visible in only a limited number of outcrops and so, for the most part, the location of the contact has been inferred. Since there is a shortage of well data in this area, only certain generalities may be made about the hydrogeology of the cataclastic rocks.

The cataclastic rocks are distinguished by their closely spaced jointing. The many joints and fractures along the eastern edge of this unit form a fault-shear zone which is in line with the Triassic faults to the southwest. It is reasonable to expect that these closely spaced joint sets, and especially the fault-shear zone, have good potential for yielding ground water.

Jointing is also a feature of the Petersburg granite but is not as much in evidence. In Henrico County the Petersburg granite lies to the south and east of the cataclastic rocks. Outcrops are visible all over the western half of the county and in the bed of the James River in the Fall Zone. The formation is found at depth to the east of this area below Coastal Plain sediments. Depths of wells in the Petersburg granite range from 9.4 meters (31 feet) to over 151.5 meters (500 feet). The average depth of these wells in the records of the State Water Control Board is 82.7 meters (273 feet). Yields of wells in the Petersburg granite are very variable. Yields range from less than

Fig. 12. A Schematic Diagram Showing the Subsurface Cross-Section of Typical Fractured and Jointed Piedmont Rocks.



SOURCE: STATE WATER CONTROL BOARD – PRO

3.78 lpm (1 gpm) to over 757 lpm (200 gpm) with 216 lpm (57 gpm) being the average. It must be remembered that these yields do not normally increase with depth, but rather with the degree of jointing and the thickness and nature of overlying materials. When plotted and contoured by computer, the yield data indicates an increase to the east in the section of the county underlain by the Petersburg granite. This is probably a reflection of an increase in thickness of the saprolite or of the coarse, regressive, terrace sediments of the overlying Coastal Plain.

Triassic Rocks (225 to 190 MYBP)

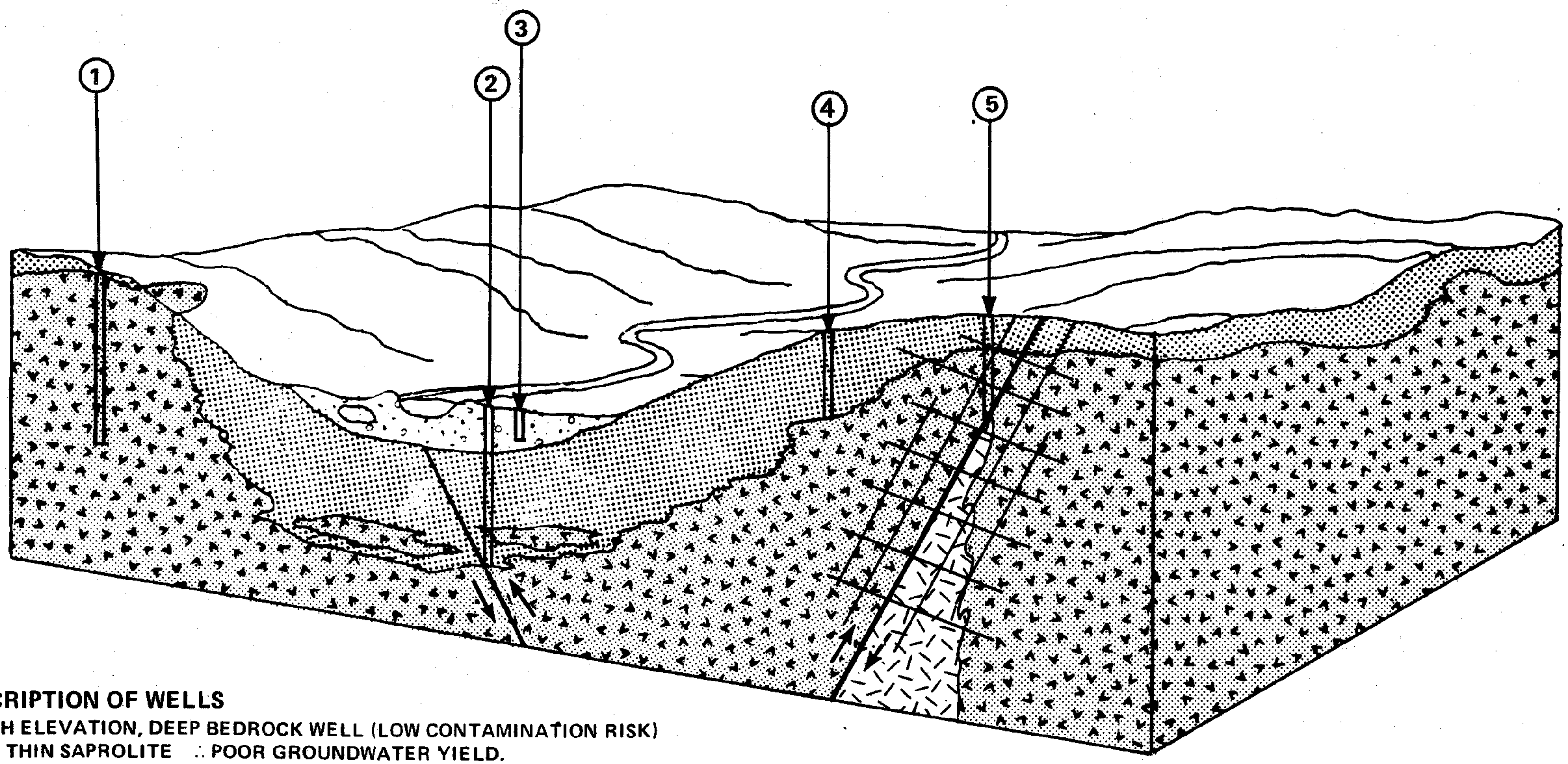
Regionally, Triassic rocks exhibit hydrogeologic characteristics similar to the Petersburg granite. This is due to the fact that the diagenetic forces which consolidated them have decreased their porosity and permeability.

There are four wells in the records of the State Water Control Board which penetrate the Triassic rocks in Henrico County. Three of these wells are in the Coastal Plain section of the county. Their depths range from 184.8 to 215.8 meters (610 to 712 feet). The Triassic-like rocks found in these eastern wells were overlain by the Patuxent and later formations of the Coastal Plain making yield data unreliable. However, State Water Control Board Well No. 143-90, drilled for the Lower Tuckahoe Service Company, is apparently entirely within the Triassic outcrop area. Its yield of 144 lpm (38 gpm) and depth of 60.6 meters (200 feet) appears typical of other Piedmont wells.

Although ground water yields vary considerably with location, certain techniques have been developed to assist in locating potential well sites. One such technique known as fracture trace analysis consists of trying to locate fracture zones using topographic maps and aerial photographs. Since fractured areas are more subject to weathering and erosion, they often appear as topographically low areas. By observing topography and drainage patterns, well sites can be located over the subterranean fractures. Many pegmatites (coarse-grained igneous dikes and veins) develop into highly-permeable gouge zones due to weathering action. These pegmatitic gouge zones store ground water and can yield adequate domestic supplies. Unfortunately, the possibility of high iron concentrations and surface water contamination make the majority of them less than ideal ground water sources.

Saprolite is found as the surface cover for most of the Piedmont area (Figure 12). It ranges in thickness from zero meters, at a bedrock outcrop, to 30 meters (100 feet) or more in highly-weathered, topographically-low areas. The saprolite has hydrogeologic characteristics similar to unconsolidated sediments, but its permeability is considerably lower due to its non-transported nature and high clay content. Much of the infiltrating rainwater collects at the saprolite-bedrock interface due to the impermeability of the solid bedrock below. Most shallow bored wells in the Piedmont tap this zone for their ground water supply [Figure 13 (well # 4)].

Fig. 13. Typical Ground Water Well Locations in the Piedmont

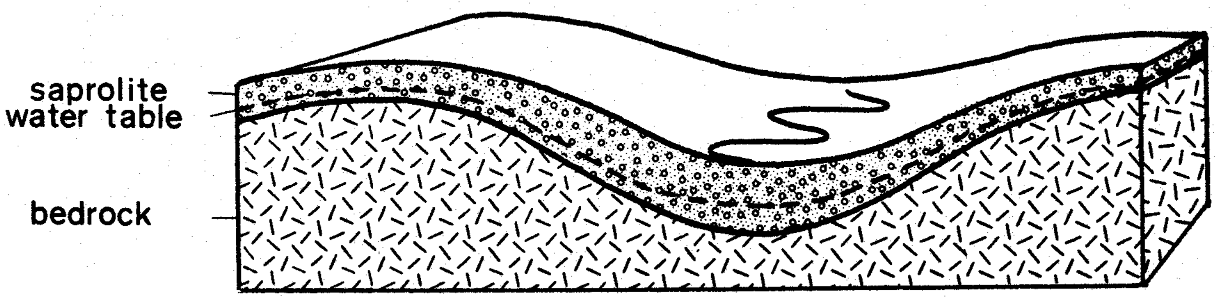


DESCRIPTION OF WELLS

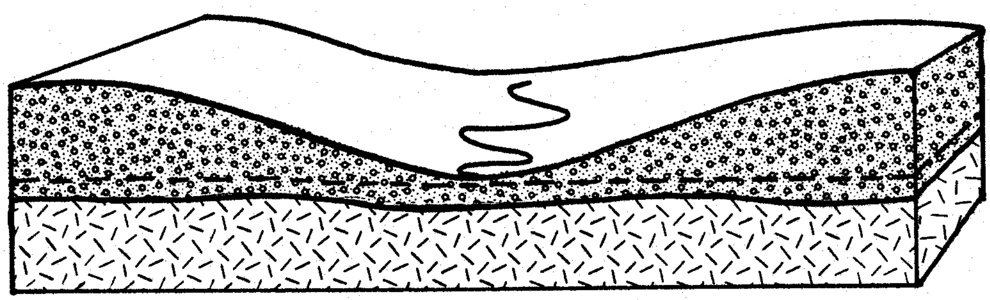
1 HIGH ELEVATION, DEEP BEDROCK WELL (LOW CONTAMINATION RISK)
   – THIN SAPROLITE ∴ POOR GROUNDWATER YIELD.
   – NO FRACTURE INTERSECTIONS ∴ POOR GROUNDWATER YIELD.
2 LOW ELEVATION WELL (HIGH CONTAMINATION RISK IN UPPER FORMATIONS)
   – THICK STREAM ALLUVIUM AT TOP ∴ GOOD YIELD.
   – THICK SAPROLITE BELOW ∴ GOOD YIELD.
   – BEDROCK FRACTURE ZONE AT BOTTOM ∴ EXCELLENT YIELD.
3 LOW ELEVATION WELL (HIGH CONTAMINATION RISK)
   – SHALLOW STREAM ALLUVIUM ∴ GOOD YIELD
4 HIGH ELEVATION, THICK SAPROLITE WELL TO BEDROCK (SLIGHT CONTAMINATION RISK)
   – THICK SAPROLITE ∴ FAIR TO GOOD YIELD.
5 HIGH ELEVATION, SAPROLITE AND BEDROCK WELL (SLIGHT CONTAMINATION RISK)
   – THICK SAPROLITE ∴ FAIR TO GOOD YIELD.
   – BEDROCK FRACTURE AND JOINT INTERSECTIONS ∴ EXCELLENT GROUNDWATER YIELD.

SOURCE: STATE WATER CONTROL BOARD – PRO

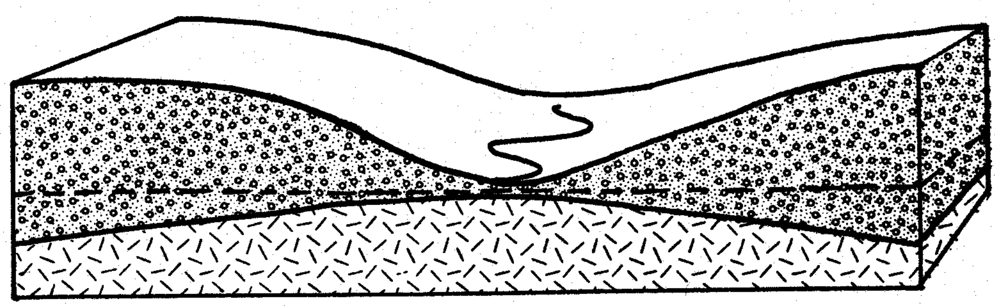
Fig. 14. Common Examples of Rock-Saprolite Relationships in the Piedmont and the Effects They Have upon the Ground Water.



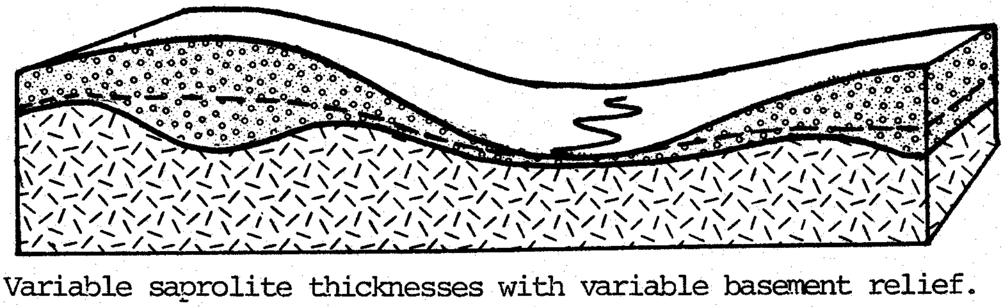
Thick saprolite in topographically-low area with generally parallel basement relief.



Thick saprolite in topographically-high areas with minor basement relief.



Thick saprolite in topographically-high areas with broad basement relief.



Variable saprolite thicknesses with variable basement relief.

Stream alluvium and terrace deposits along streams and drainageways also supply some shallow wells in the Piedmont [Figure 13 (well # 2)]. The unconsolidated sediments usually contain adequate ground water supplies for domestic purposes. Most of these supplies are very susceptible to fluctuations in precipitation and nearby stream and drainageway contamination. Of all such deposits, the alluvial sediments with coarse constituents are the best potential ground water source.

Coastal Plain Hydrogeology

The major ground water production aquifers in the Coastal Plain section of Henrico County include the Paleozoic and Triassic "basement complex" rocks, the principal artesian aquifer (the Patuxent Formation of Cretaceous age), the upper artesian aquifer (late Cretaceous and Tertiary), and the near surface water table aquifers.

While the principal aquifer can be relied upon to produce a steady, abundant supply of water, it is often more economical to tap shallower units with a bored well for domestic or farm use.

Paleozoic "Basement Complex" (330 MYBP)

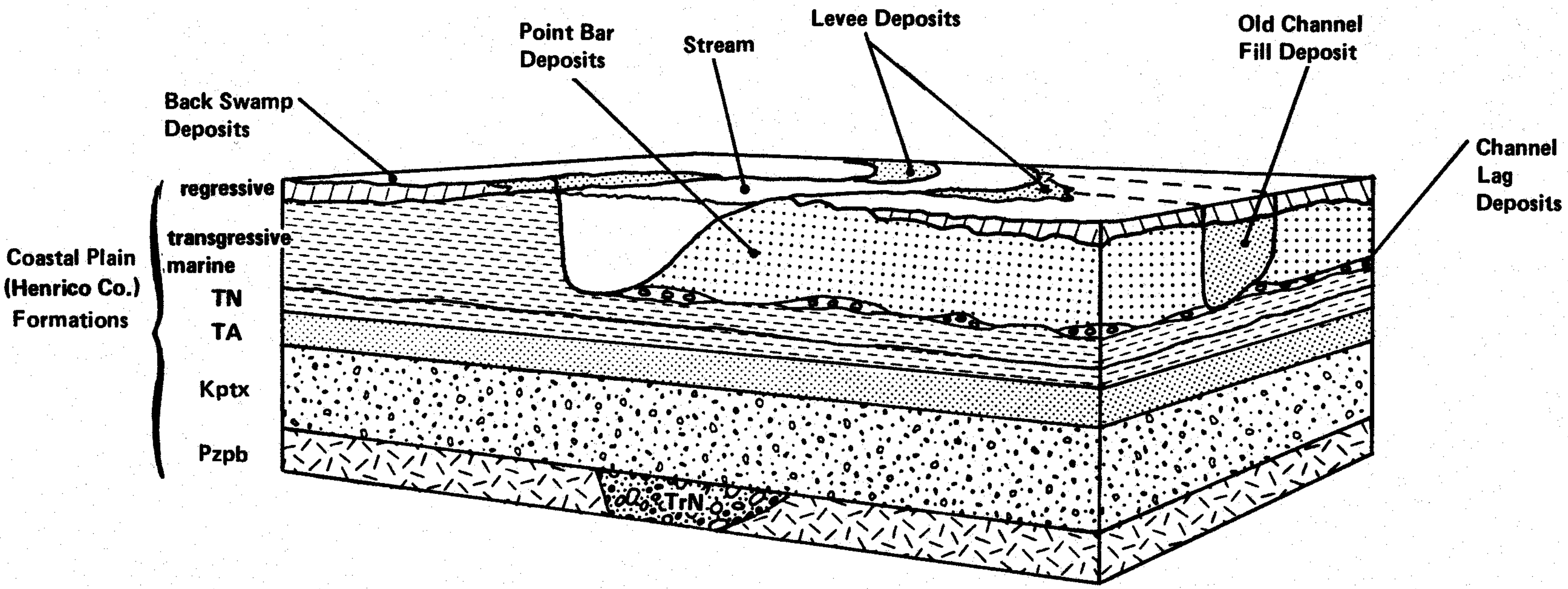
Just as there are Triassic rocks tapped by Coastal Plain wells, there are also wells drilled into the Petersburg granite beneath the Coastal Plain. The water bearing characteristics of these rocks at depth in the Coastal Plain are strictly related to the degree to which they are fractured. Wells 143-1, 143-6, and 143-7 in the files of the State Water Control Board have been identified as being in the Petersburg granite. Their depths, ranging from 69.2 to 86.9 meters (227 to 285 feet) bracket the average depth for all Petersburg wells cited before. The yields of these wells range from 26.5 to 291 lpm (7 to 77 gpm). Because these wells are drilled through the overlying Coastal Plain aquifers, the entire yield cannot be attributed to the Petersburg granite.

Cretaceous Period (135 to 63 MYBP)

The lowest Cretaceous unit is the Patuxent Formation (Kptx). This aquifer has proven to be the best source of water in deep wells on the Coastal Plain. This is due to the highly permeable nature of the coarse sands and gravels which make up the formation, its thickness, and its wide areal extent. The presumed subsurface extent of this formation is shown in Figure 16.

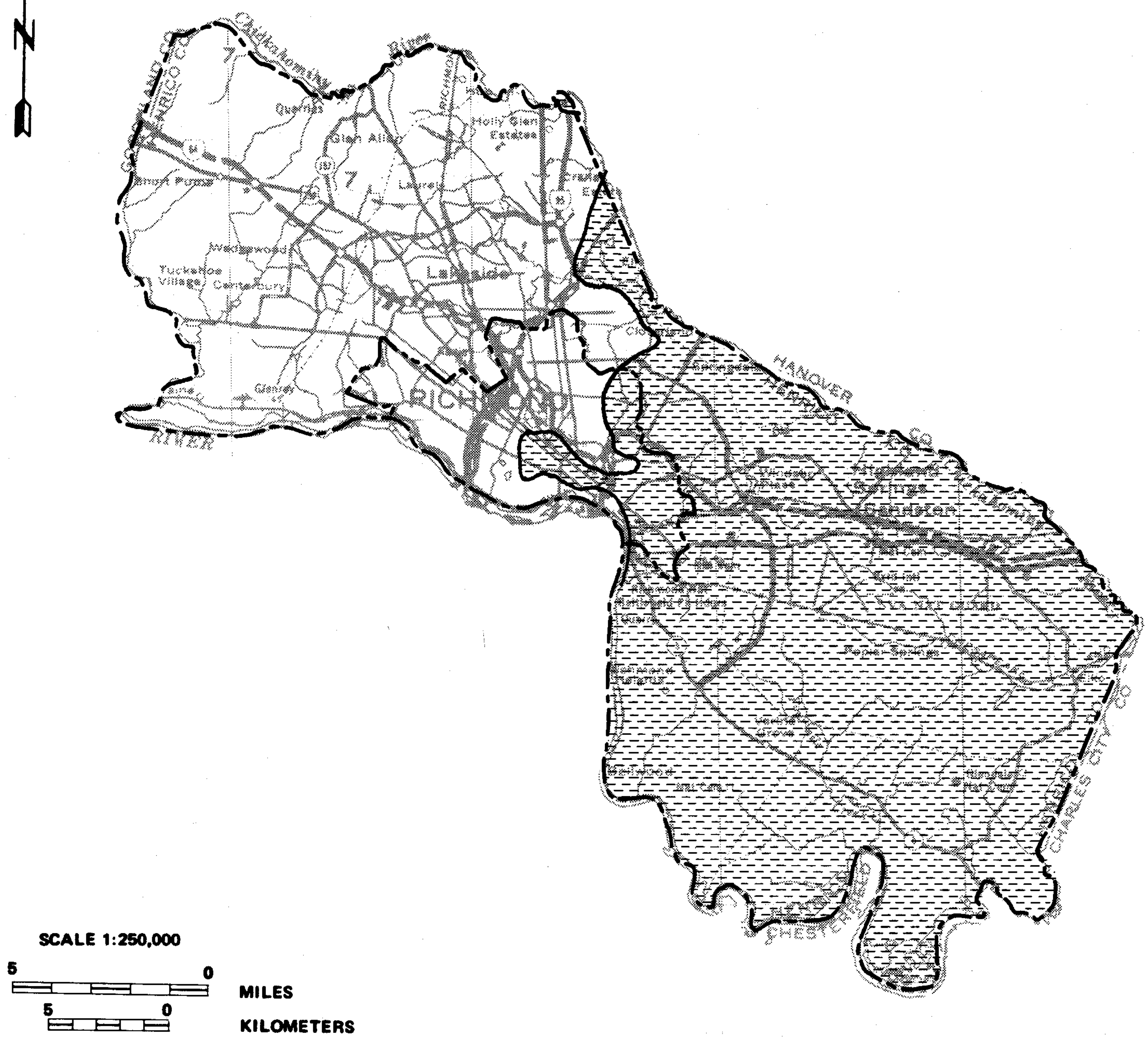
The thickness of the Patuxent formation is not consistent due to the near-shore nature of its deposition as a series of deltas. The high energy regimes of the distributary channels deposited coarse sediments

Fig. 15. Schematic Cross-Section Showing Alluvial Deposits of a Typical Coastal Plain Stream.



SOURCE: STATE WATER CONTROL BOARD – PRO

Fig. 16. Extent of Patuxent Formation in Henrico County and Richmond North of the James River.



SOURCE: DANIELS AND ONUSCHAK, 1974; TIEFKE, 1973 into "basement complex" topographic lows. As the basement lows filled, finer-grained sediments were deposited on the flanks of basement highs. As later formations were deposited on top of these sediments, the fine grained deposits were compacted to a greater extent than the coarse grained ones. Report of Investigations 38, VDMR (1974) contains a plate depicting a thinner area of the Patuxent in the area of Byrd International Airport. This corresponds to an area of lower well yield.

The yields from the Patuxent Formation range from 22.7 to 2649 lpm (6 gpm to 700 gpm) with an average of 412 lpm (109 gpm). Depths of wells drilled into the Patuxent Formation average 89.6 meters (294 feet) with the shallowest in the records of the State Water Control Board being 50.6 meters (166 feet) and the deepest being 181.3 meters (595 feet).

In addition to yield and depth there are other more precise methods which may be used to evaluate an aquifer's ground water transmission capacity. Often well data can be used to calculate hydraulic conductivity, an approximate value for the true permeability of an aquifer. High hydraulic conductivity values indicate a more permeable zone of rock with a greater potential for yielding ground water. Hydraulic conductivity may be computed as follows:

$$K = \frac{24}{T} \cdot \frac{Q}{Sh\pi D}$$

Where: K = hydraulic conductivity in Meinzers
T = total hours pumped
Q = total gallons discharged
S = drawdown in feet
h = thickness in feet of permeable section of the aquifer
π = 3.14159
D = diameter of the hole in feet

To modify this formula for gallons per minute:

$$K = \frac{Q \cdot 1440}{Sh\pi D}$$

As an example of this measurement, the hydraulic conductivity (average permeability) can be calculated for State Water Control Board Well # 143-3. The discharge or yield is 6 gpm. The drawdown (S) is 40 feet with the screened section of the aquifer (h) equaling 30 feet. The diameter of the hole (D) is 0.5 feet. Therefore:

$$K = \frac{(6\text{ gpm})(1440\text{ minutes/day})}{(40')(30')(3.14159)(0.5')}$$

$$K = \frac{8640}{1384.96} = 4.58 \text{ gallons per minute per square foot per foot of drawdown.}$$

Hydraulic conductivity values derived for those Patuxent Formation wells with complete data are shown in Table IV. To understand the potential yield of an aquifer, the hydraulic conductivity (permeability) is the best but most complex method.

Specific capacity is another value used in evaluating well potential. This value can be obtained by dividing the well yield by the measured drawdown for a specific period of time and modifying the result by the variables of well radius and the portion of the aquifer being used. Because of the difficulty in obtaining the values for aquifer thickness, no attempt was made to derive these values for this report.

The Patuxent Formation has been and can be an abundant source for ground water in Henrico County. An examination of well yield data for wells drawing on the Patuxent Formation shows an eastward increase in yield. This increase corresponds to the thickening of the Patuxent Formation to the east. An area of low yield just northeast of the James River, in the general area of Varina, may correspond to a thinning of the formation due to the area being between deltaic lobes, or from erosion of the formation due to meandering of the river.

Late Cretaceous and Tertiary Periods (70 to 2 MYBP)

The prevalence of wells in the Patuxent Formation is in stark contrast to the scarcity of wells in the marine transgressive sequence of beds above the Patuxent (Figure 15). State Water Control Board records contain only 6 wells which bottom in one of these marine beds. Two of the wells, numbers 124 and 310, are deep wells, 57.9 to 70.7 meters (190 and 232 feet), whereas the other four are relatively shallow, between 12.2 and 15.2 meters (40 and 50 feet deep). Yield data for these shallower wells is lacking. It is likely that the bulk of the water in these wells has accumulated in the overlying regressive sands and gravels. This is true of well number 304. In this well further drilling into the Miocene marl did not increase yield appreciably. Although Cederstrom's (1957) study postulated otherwise, State Water Control Board data indicates that these transgressive marine sediments are a vastly inferior aquifer in comparison to overlying and underlying beds.

Late Tertiary and Quaternary Periods (11 MYBP to Present)

The regression of the sea during the Late Miocene caused a change in the nature of the sediments being deposited. These coarse sands and occasional gravels are quite permeable. For this reason a large number of wells have been bored or dug into these beds to provide adequate water supplies for small farms and domestic uses. The State Water Control Board files indicate that these wells average 12 meters (39 feet) in depth.

TABLE IV HYDRAULIC CONDUCTIVITY - PATUXENT AQUIFER

SWCB WELL #	HYDRAULIC CONDUCTIVITY (GPM per Square Foot Per Foot of Drawdown)
3	4.58
5	31.84
8	31.87
19	57.29
20	30.63
27	76.39
31	16.68
32	26.43
34	93.79
36	44.87
39	285.21
40	24.88
62	16.38
63	68.82
66	21.85
69	44.98
70	11.85
75	73.79
79	73.63
80	41.67
87	55.84
91	22.12
92	51.16
93	3.27
99	25.47
159	57.30
169	46.67
187	41.58
200	44.18

TABLE V

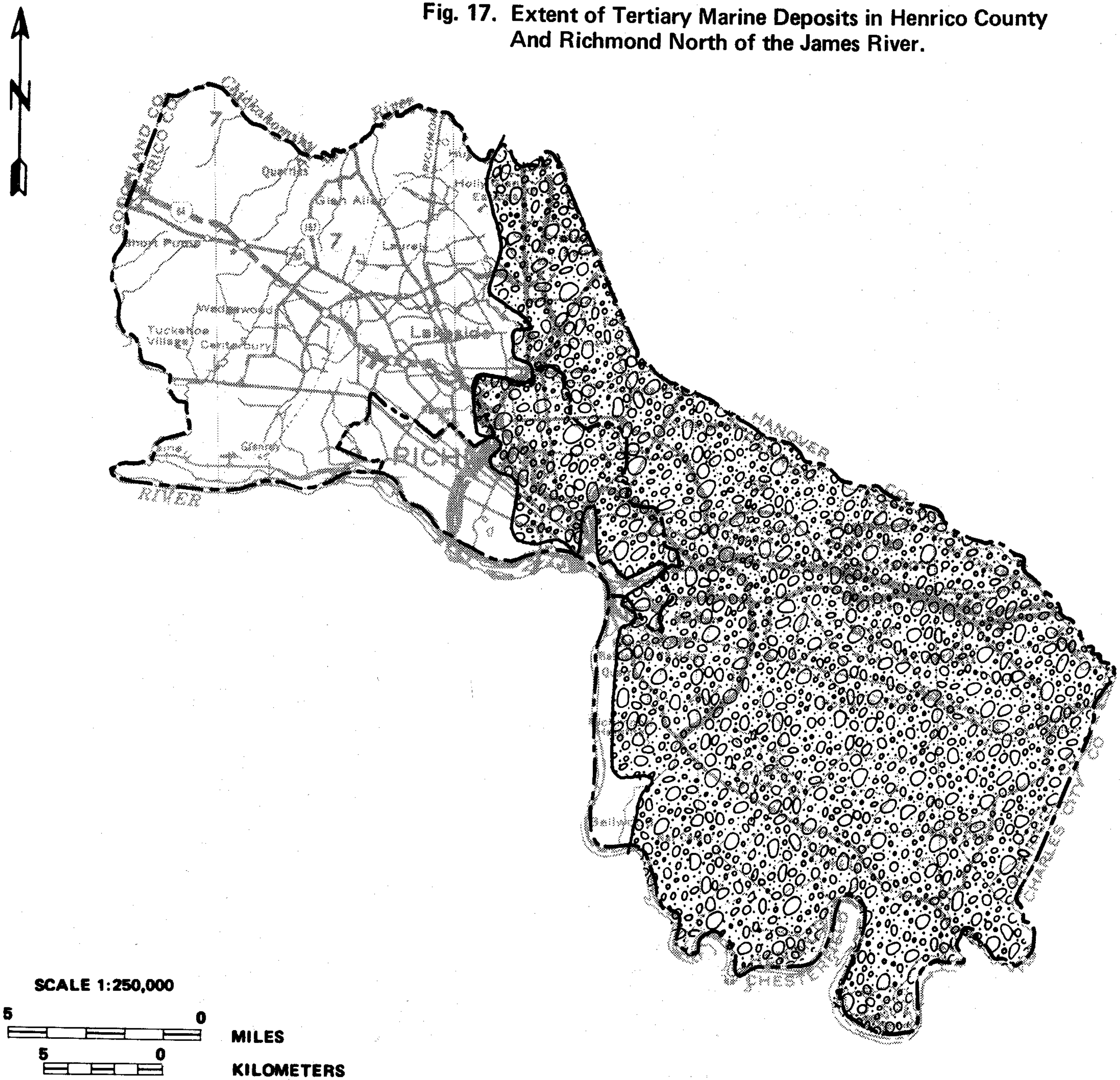
COMMON PERMEABILITIES AND

HYDRAULIC CONDUCTIVITIES (at 60°F)

Groundwater Production	Permeability (Darcies)	Hydraulic Conductivity (Meinzers)	Rock or Soil Material
Very Good Flow	over 1000	over 18,200	unconsolidated, clean, well-sorted sand and gravel, open coquina, open fractures and fault zones, open limestone caverns and solution vugs, open breccia
Good Flow	5.5-1000	100-18,200	packed, clean gravel, dune sand, fine, unconsolidated, clean sand, packed, clean coarse sand
Average Flow	0.275-5.5	5-100	moderately-indurated-and-cemented, clean, well-sorted sandstone, silt, loess
Low Flow	0.11-0.275	2-5	very-indurated-and-cemented, clean sandstone and siltstone, poorly-sorted sand and sandstone
Very Low Flow	0.055-0.11	1-2	sucrosic dolomite, quartzite, clayey siltstone and sandstone
No Flow	less than 0.055	less than 1	clay, shale, mudstone, unweathered, crystalline limestone and dense dolomite, unweathered igneous and metamorphic rocks, graywack, salt, iron ore, massive chert

SOURCE: SWCB-PRO, BWCM

Fig. 17. Extent of Tertiary Marine Deposits in Henrico County And Richmond North of the James River.



SOURCE: DANIELS AND ONUSCHAK, 1974; TIEFKE, 1973

It must be borne in mind that this aquifer is first to be affected by seasonal fluctuations in the water table but generally remains an adequate low-yield ground water producer even during times of drought.

The last of these formations to be deposited is the Quaternary alluvium. Although these poorly sorted clays, sands and gravels are found over a large area, they are relatively thin and their position and thickness fluctuates with the amount and velocity of the water flowing through the drainageways of the county. For this reason they are not considered important aquifers.

Fall Zone Hydrogeology

The border between the Piedmont rocks to the west and the Coastal Plain sediments to the east is the Fall Zone (Figure 3). This zone trends north-south, parallel to, and in the vicinity of, Interstate 95. An abrupt decrease in land elevation is noted in the Fall Zone. This difference in elevation is displayed not only in the topography but also by the change in velocities of the streams and rivers and by the many Petersburg granite outcrops.

Sources for ground water along the Fall Zone are rather limited and include the saprolite overlying the Petersburg granite; the thin, onlapping, undifferentiated, Coastal Plain sediments; and the underlying Petersburg granite bedrock. The best source of ground water in the Fall Zone is from the deeper, underlying Petersburg granite. Fractures and joints in the granite offer a greater potential for good ground water yields than the overlying saprolite and unconsolidated materials (Figure 11).

Coastal Plain Fault Zone

It is hoped that areas affected by Cenozoic faulting will soon be delineated in the area. Faulting of the Coastal Plain beds is significant for three reasons. First, by offsetting beds vertically the fault makes it difficult to predict the depth at which a water bearing formation can be found. Second, this vertical displacement of beds can place an impermeable bed in juxtaposition with a permeable bed. This will slow lateral recharge down dip (eastward) and cause ponding up dip of the fault. While the ponding may be desirable from a quantity standpoint, the quality of the ponded water may be affected. Ponding of water within the formation may result in an increase of dissolved solids. Third, there may be a dump zone of coarse sediments on the down-thrown block adjacent to the fault. This is especially true when sedimentation and faulting are contemporaneous. Such a zone could be expected to provide a high yield although it may be limited in extent.

CHAPTER V

GROUND WATER QUALITY

General

Ground water quality information is collected throughout the Commonwealth on a continuous basis by the staff of the State Water Control Board. The quality information obtained enables the Board to monitor ground water quality. Quality fluctuations in an area may be indicative of ground water pollution. Long term background sampling is performed in order that long term quality trends, including gradual ground water degradation, can be ascertained. All of this information is correlated with other well information to enable more efficient ground water resource management.

This chapter will discuss the methods employed in quality data collection and storage, the chemical parameters tested, and how the major quality parameters relate to the hydrogeology of an area.

Ground water quality information for Henrico County was obtained from newly completed public-use wells, records from the State Department of Health, past ground water sampling by the State Water Control Board, and ongoing ground water sampling procedures carried out by the Piedmont Regional Office. Many high-use wells, notably public supply and industrial wells, are sampled on a periodic basis, allowing a better understanding of quality changes through time and usage.

All ground water quality data for Henrico County has been stored on computer by the State Water Control Board. Sixty-three possible water-quality parameters have been recorded, with fifteen major parameters displayed on the periodically published computer print-outs.

All ground water quality information is determined by standard, approved, chemical-analysis techniques performed by the Commonwealth of Virginia Consolidated Laboratory in the Division of Environmental Sciences. The parameters tested for in each State Water Control Board ground water sample include: pH (laboratory); alkalinity/acidity (mg/l as $CaCO_3$); total solids, volatile, fixed; suspended solids, volatile, fixed; chloride; hardness, EDTA (mg/l as $CaCO_3$); nitrogen, total Kjeldahl; phosphorus, total; phosphorus, ortho; ammonia (mg/l as N); nitrite & nitrate (mg/l as N); nitrite (mg/l as N); sulphate; total organic carbon; fluoride; arsenic; cadmium; calcium; chromium; copper; iron; lead, total; magnesium; manganese; mercury, total; zinc; sodium; potassium; total coliform/100 ml-MPN; fecal coliform/100 ml-MPN; and conductivity (micro-mhos/cm). A table of major parameters and their recommended maximum concentrations is provided in Appendix II.

Almost all of the dissolved solid substances found in ground water are added as the water percolates through the subsurface. A chemical equilibrium is reached for each substance as its concentration approaches saturation levels. Temperature, pressure, and ground water volume directly affect this process. Many variables such as vegetation, amount of precipitation, pH, geology, and aquifer composition also affect ground water quality by the kinds and amounts of constituents they provide.

The usefulness of ground water is related directly to the kinds and amounts of dissolved minerals, and other chemical characteristics of the water. Unlike surface water, ground water usually contains only minor amounts of suspended solids and virtually no bacteria.

The ion concentrations of the dissolved materials are usually of prime concern in a chemical analysis. The major properties of ground water that best reflect its general quality are: hardness, specific electrical conductance, hydrogen ion concentration (pH), total dissolved solids, iron (Fe^{++}), chloride (Cl^-), fluoride (F^-), and nitrate (NO_3^-). These are usually reported in milligrams per liter units, (mg/1), which are the same as parts per million (1ppm = one part by weight of the dissolved substance contained in one million parts, by weight, of the solution).

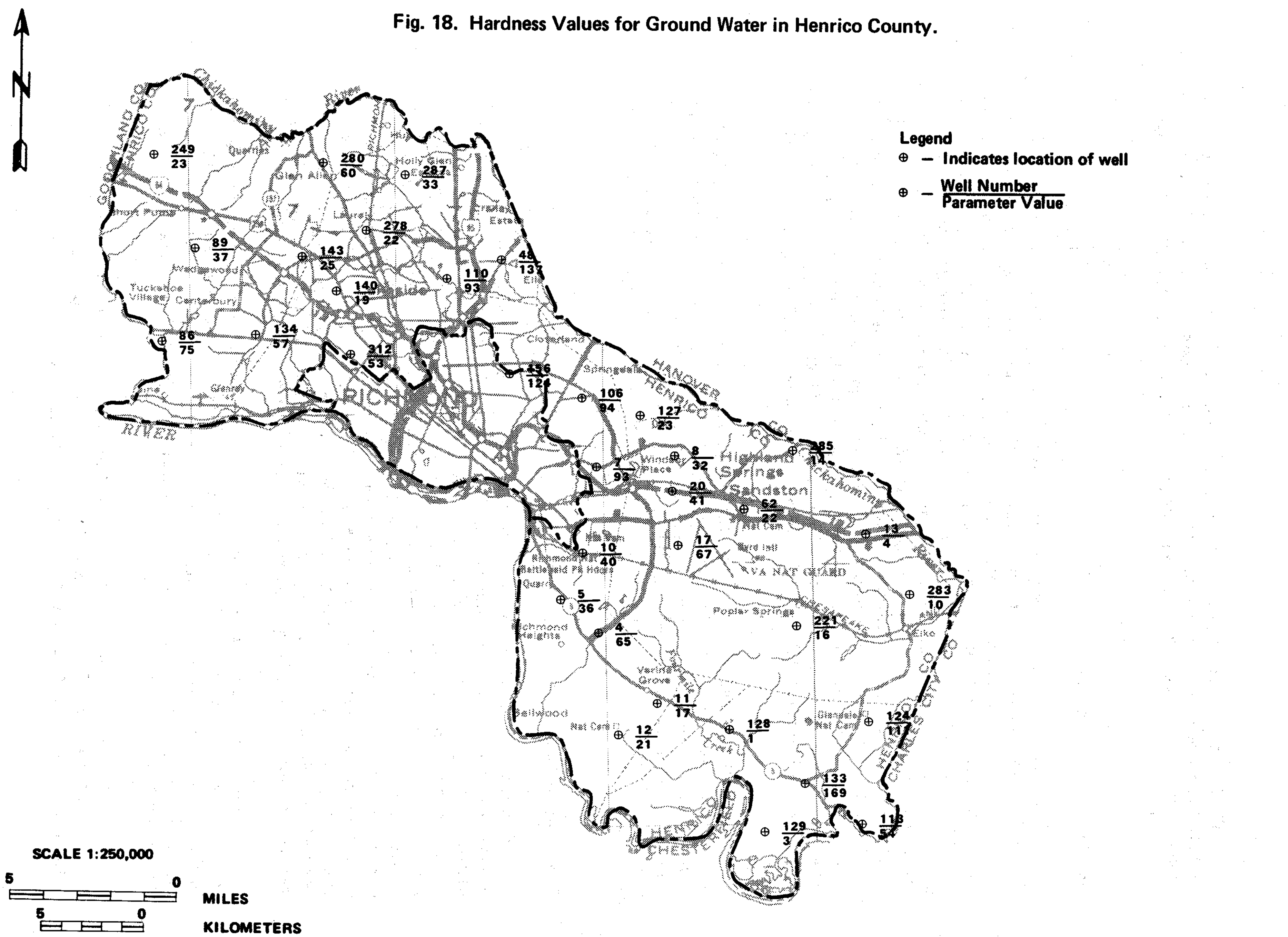
Major Ground Water Quality Parameters

Hardness

The values of this parameter indicate the "soap-wasting" properties of the water. Elements such as iron, manganese, copper, barium, lead, zinc, calcium and magnesium will combine with the components of soap to form an insoluble curd. Until these elements are precipitated out of the water, the soap will not lather and clean properly. For this reason water containing large quantities of these elements is called "hard water" and uses larger quantities of soap than "soft water". In addition, hard water will form scale upon evaporation and heating.

Of the elements listed above, calcium and magnesium are most commonly found in ground water. These elements are added as the water moves through limestone, dolomite, or unconsolidated marine sediments. Dissolved carbon dioxide in the water causes the water to act as an acid on the rocks and sediments and dissolves the elements out of the rock. Because of this chemical action, one would expect ground water hardness to vary according to rock type in Henrico County. The water hardness map verifies this (Figure 18). In the Piedmont, hardness values are low. Coastal Plain sediments add calcium and magnesium to the water due to their marine origin and fossiliferous nature. Hardness values increase east of the Fall Zone, but are notably lower in certain areas of the eastern portion of the Coastal Plain. This decline is explained by the phenomenon of cation or base exchange. Sodium in the marine sediments replaces the calcium in the water, thereby softening it.

Fig. 18. Hardness Values for Ground Water in Henrico County.



SOURCE: State Water Control Board – P.R.O.

While hard water poses no threat to health, values of over 100 parts per million may require costly softening for economical or aesthetic reasons. Excessive use of soap and frequent cleaning of boilers can prove expensive.

Specific Conductance

Specific electrical conductance refers to the ability of ground water to conduct an electric current. It is significant because it serves as a measure of the amount of elements and ions which are dissolved in the water. Although pure water is a good insulator, the addition of only a small amount of material (dissociated ions) into solution renders the solution electrically conductive and its conductivity increases as the number of dissociated ions increases. High specific conductivity values indicate undesirable water for several reasons. Higher conductivity in ground water will accelerate corrosion of iron and steel due to the increased electrolytic action. Also, water supplies with high conductivity are unsuitable for use in fire fighting because of the danger of open circuits grounding themselves through the stream of water used to extinguish the fire.

Specific conductance values for the lower artesian aquifer (Patuxent Formation) have been plotted in Figure 20. The figures are relatively low and no particular trend can be noticed. In Figure 19 these values are depicted countywide for all other aquifers in the county. Values are highest along the Fall Zone and in the areas to the southeast of the Fall Zone.

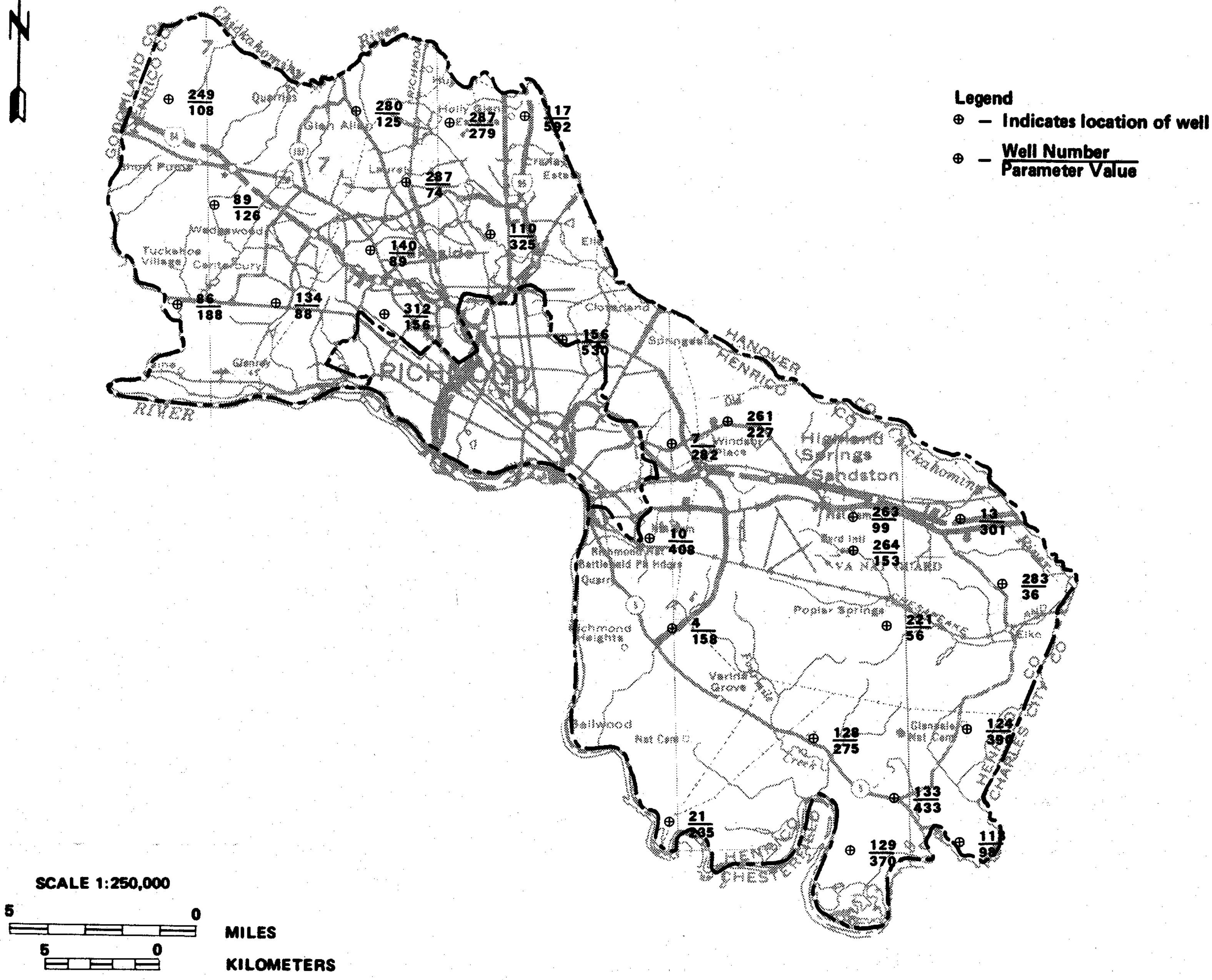
Total Dissolved Solids (TDS)

The total dissolved solids values reflect the total amount of dissolved (dissociated) substances in the water. For this reason the value serves as a generalized indicator of ground water quality. The value is obtained by evaporating a quantity of the water sample and weighing the residue or by computation from specific conductivity figures. Ground water with greater than 1000 mg/l (TDS) is not desirable both for the corrosion potential mentioned above and for the cumulative effect the dissolved substances may have on the taste of the water. While concentrations greater than 500 mg/l (TDS) may not be unhealthy, concentrations less than 500 mg/l are preferred for both aesthetic reasons and for the smaller amount of scale precipitated in industrial equipment.

In Henrico County values for total dissolved solids range from a low of 3 mg/l to a high of 2043 mg/l. Total dissolved solids concentrations in most wells in the county range from 50-100 mg/l with wells from the Patuxent Formation tending to have higher concentrations than wells in the Petersburg granite.

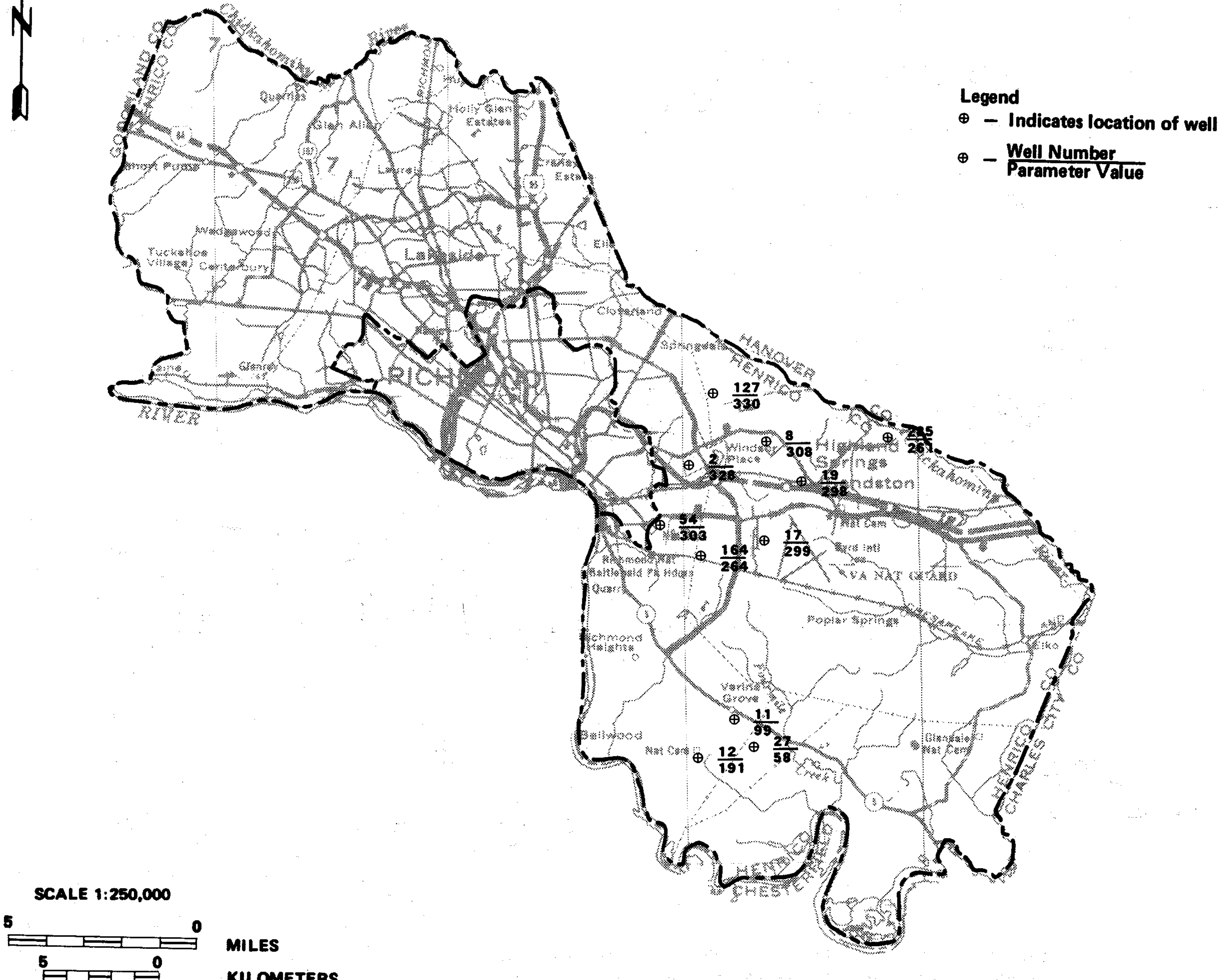
The values for total dissolved solids are plotted in Figure 21. As noted in the map for conductivity, the highest values are found around and to the southeast of the Fall Zone.

Fig. 19. Specific Conductivity of Ground Water in Henrico County (exclusive of the Patuxent Formation) (micro-mhos/cm).



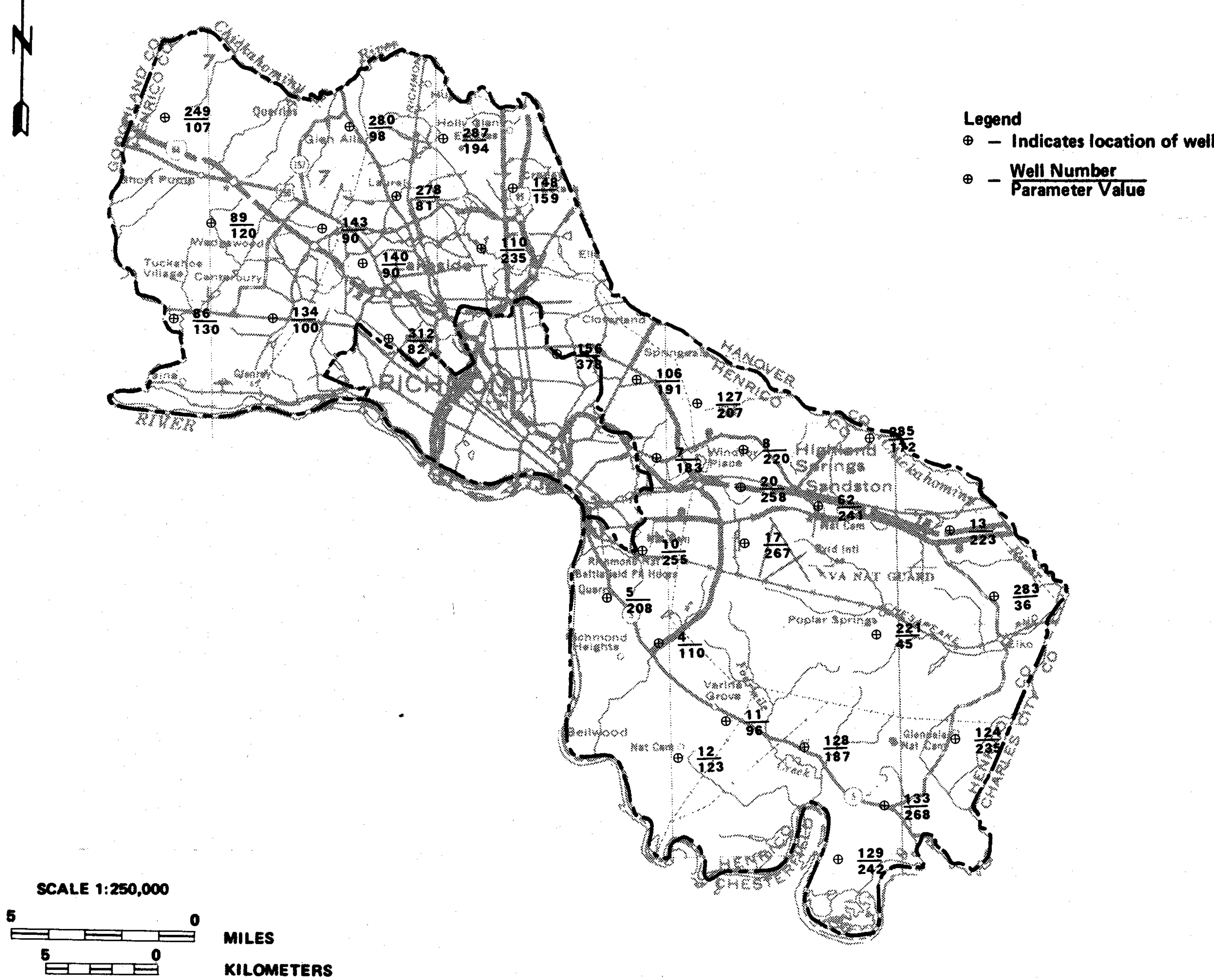
SOURCE: State Water Control Board – P.R.O.

Fig. 20. Specific Conductivity of Ground Water in the Patuxent Formation in Henrico County (micro-mhos/cm).



SOURCE: State Water Control Board – P.R.O.

Fig. 21. Dissolved Solids in Ground Water in Henrico County.



SOURCE: State Water Control Board – P.R.O.

Hydrogen Ion Concentration (pH)

An increase in the hydrogen ion concentration (H^+) causes water to act like an acid and exhibit a characteristically low pH value. Values for pH range from 0 to 14, with 0 being most acidic, 14 most basic (alkaline), and 7 representing a neutral solution. Each unit of pH indicates a 10-fold change in the hydrogen ion concentration.

Most ground water has its pH controlled by the carbon dioxide-bicarbonate relationship. An increase in dissolved carbon dioxide makes the water more acidic due to the production of carbonic acid. Any dissolved bicarbonate will make the ground water more basic (alkaline). The equilibrium between these acidic and basic components determines most ground water pH. Since carbon dioxide can escape rapidly from a water sample, thereby reducing its acidity, timely field pH tests are more representative of true pH than delayed laboratory tests. In the Ground Water Quality Listing (see Appendix V), the high pH values, found in State Water Control Board wells with low listed numbers, relate to the loss of acid forming carbon dioxide from the samples before laboratory testing could be performed. In recent years, more efficient equipment has enabled more expedient laboratory analysis, and this is presumed to be reflected in the lower pH values.

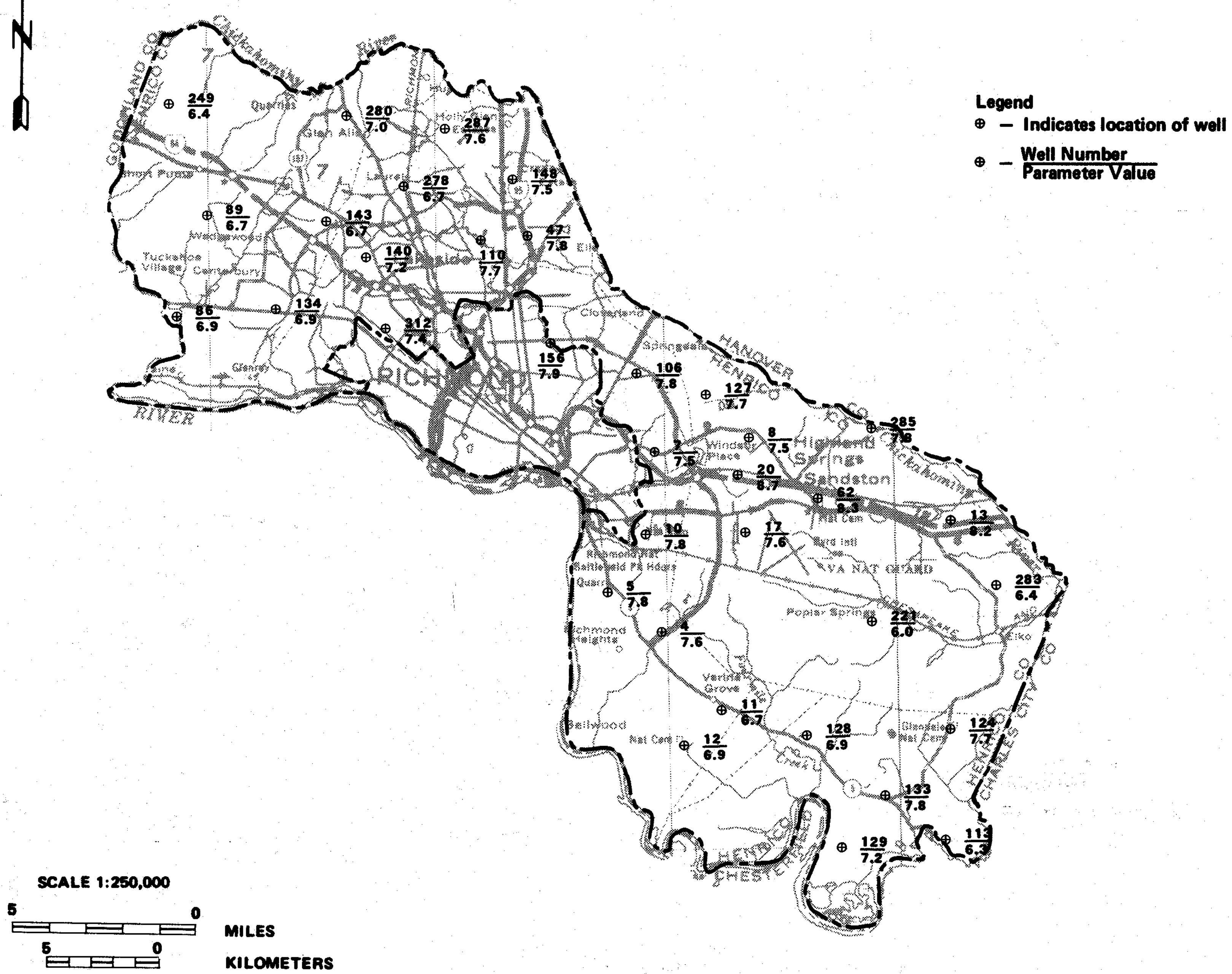
The corrosion of plumbing materials by ground water with a low pH value can degrade the quality of the water. Not only is a sour taste imparted to water with a pH less than 4, but the corrosion of concrete, zinc-galvanized, or copper pipes will add additional impurities to the water. The presence of hydrogen ions in water affects the degree of chemical dissociation of many substances. The effect of additional hydrogen ions often makes the solution more toxic as it results in a larger part of the substance remaining dissolved in the water.

Most ground water in Henrico County showed a pH in the acceptable range of 5.5-8.0. While some wells showed values in excess of 8, these may reflect older sampling methods more than local trends. See Figure 22.

Iron (Fe^{++})

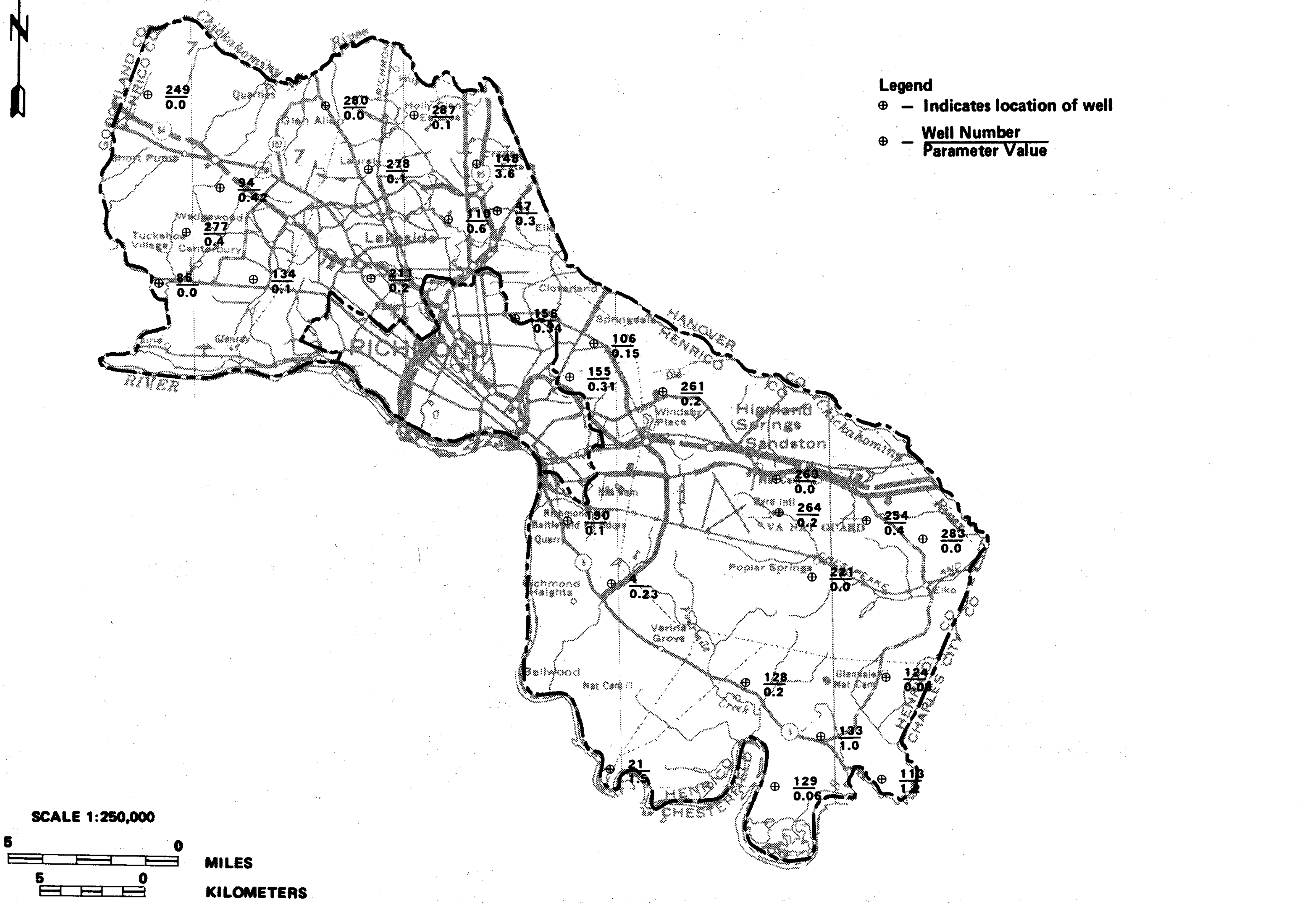
Iron is present in most water supplies, but in amounts above 0.3 mg/1 staining of clothes and plumbing fixtures as well as incrustation of well screens and pipes occurs. Some industries require the iron concentration of their process water to be less than 0.1 mg/1. This value is sometimes difficult to achieve since the average concentration in ground water ranges from 1 to 5 mg/1. Aeration can usually reduce this value to about 0.1 ppm (Johnson, 1975). Physiologically, lower levels of iron have been noted to have no adverse effect on humans or animals. The human body actually requires 5 to 6 milligrams of iron per day.

Fig. 22. Hydrogen Ion Concentration (pH) of Ground Water in Henrico County.



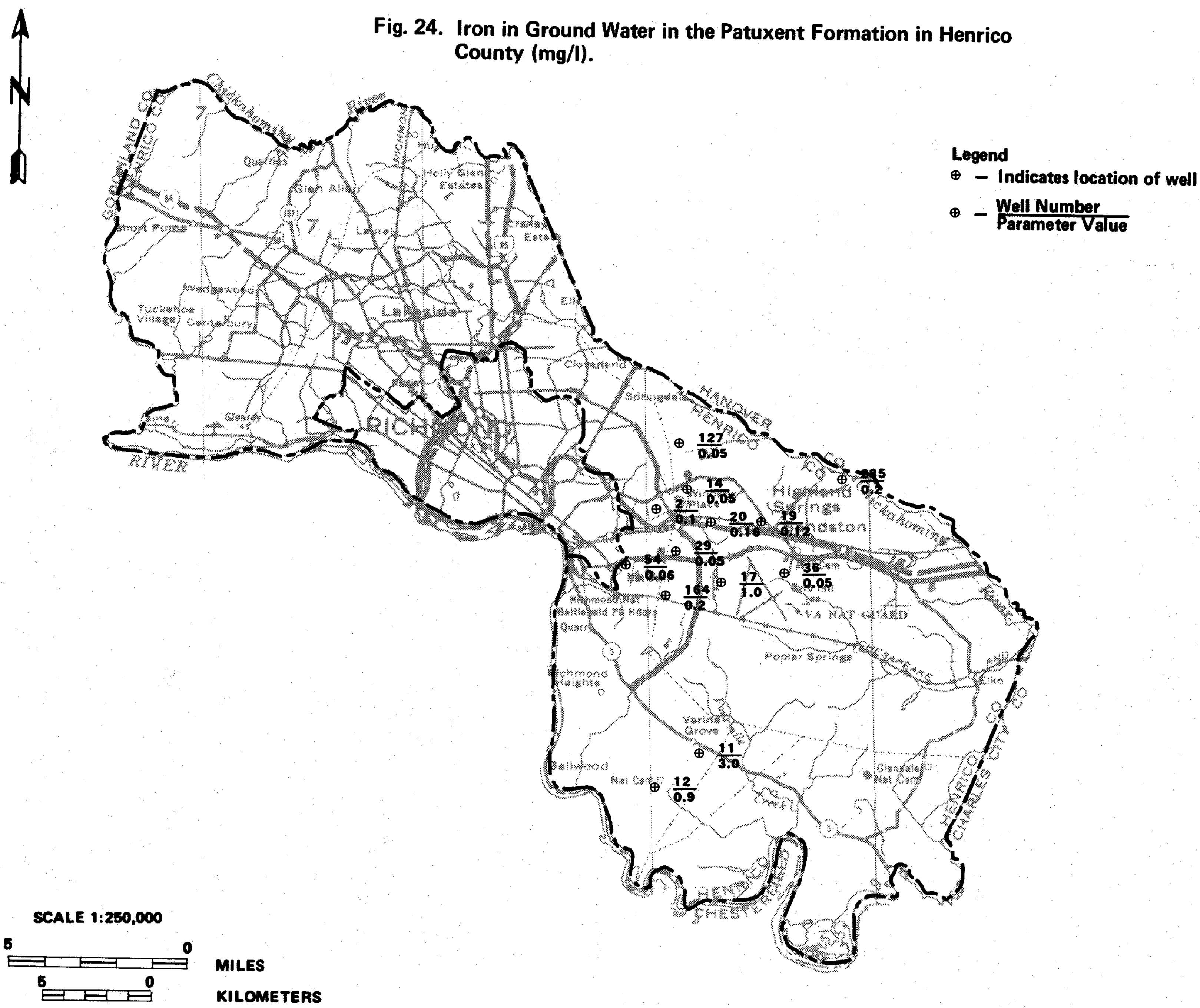
SOURCE: State Water Control Board – P.R.O.

Fig. 23. Iron in Ground Water in Henrico County (exclusive of the Patuxent Formation) (mg/l).



SOURCE: State Water Control Board – P.R.O.

Fig. 24. Iron in Ground Water in the Patuxent Formation in Henrico County (mg/l).



SOURCE: State Water Control Board – P.R.O.

Ground water acquires iron from various iron-bearing minerals (biotite, glauconite, hornblende, pyroxene, and others) during the percolation process. The amount of iron uptake depends largely upon the pH of the water. The lower the pH the more iron will go into solution. Acidic ground water will dissolve the iron from well casing, piping, and pump parts. Iron-bearing ground water may appear clear when initially pumped, but upon contact with the oxygen of the air a rusty iron precipitate appears. Iron bacteria such as crenothrix flourish in iron bearing waters and such bacteria produce pipe clogging precipitates.

Iron concentrations in Henrico County ground water range from undetectable to more than eight parts per million. Most of these values are within the desirable 0-.30 mg/l range. Concentrations from wells tapping the sands deposited during regression of the sea are generally lower in iron. The Patuxent Formation also appears to contain water with low iron concentrations. Often wells with high iron concentrations have had low concentrations in other samples. While the Petersburg granite appears to contain water with acceptable concentrations, there are overall higher concentrations noted from wells in the Piedmont section than in well samples from the Coastal Plain section.

Data plots of ground water iron concentrations in the county are shown in Figures 23 and 24.

Chloride (Cl^-)

The minerals which make up igneous rocks generally contain very little chloride, especially the forms of chlorine which are readily soluble. The chloride content of sea water is about 19,000 mg/l (Johnson, 1975). For these reasons one would expect to find larger amounts of chloride in Coastal Plain, marine-deposited sediments than in those rocks west of the Fall Zone. This is generally true, although the chloride levels vary a great deal in the county. For the most part, chloride levels in Henrico County fall within the 1-10 mg/l range with several well samples containing over 10 mg/l chloride.

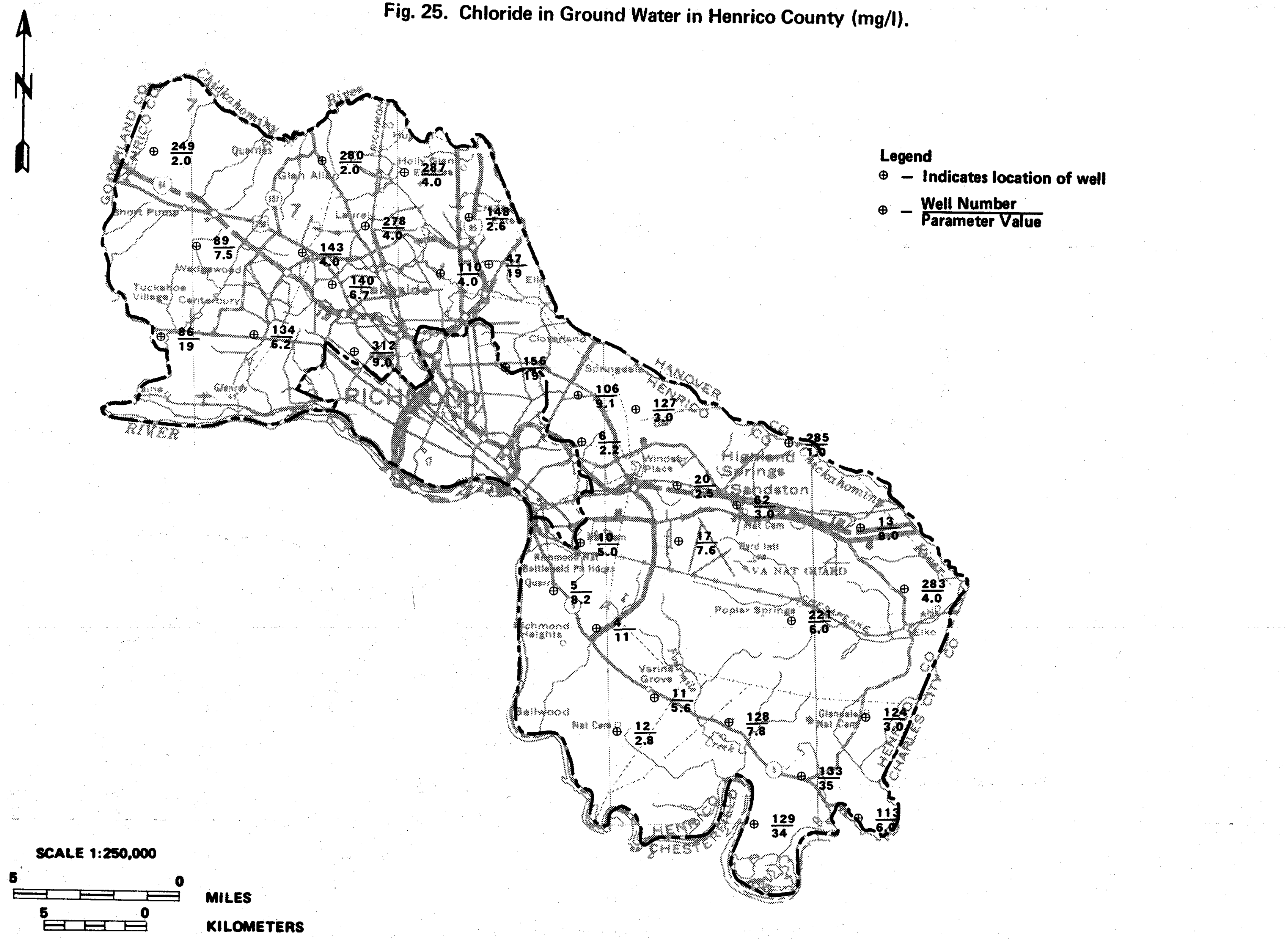
Except in cases where an individual is suffering from heart or kidney disease, chloride concentrations below the 250 ppm level pose very little health risk.

The map of chloride concentrations is displayed in Figure 25. Higher concentrations can be noted in the Fall Zone and appear in various locations throughout the eastern part of the county.

Fluoride (F^-)

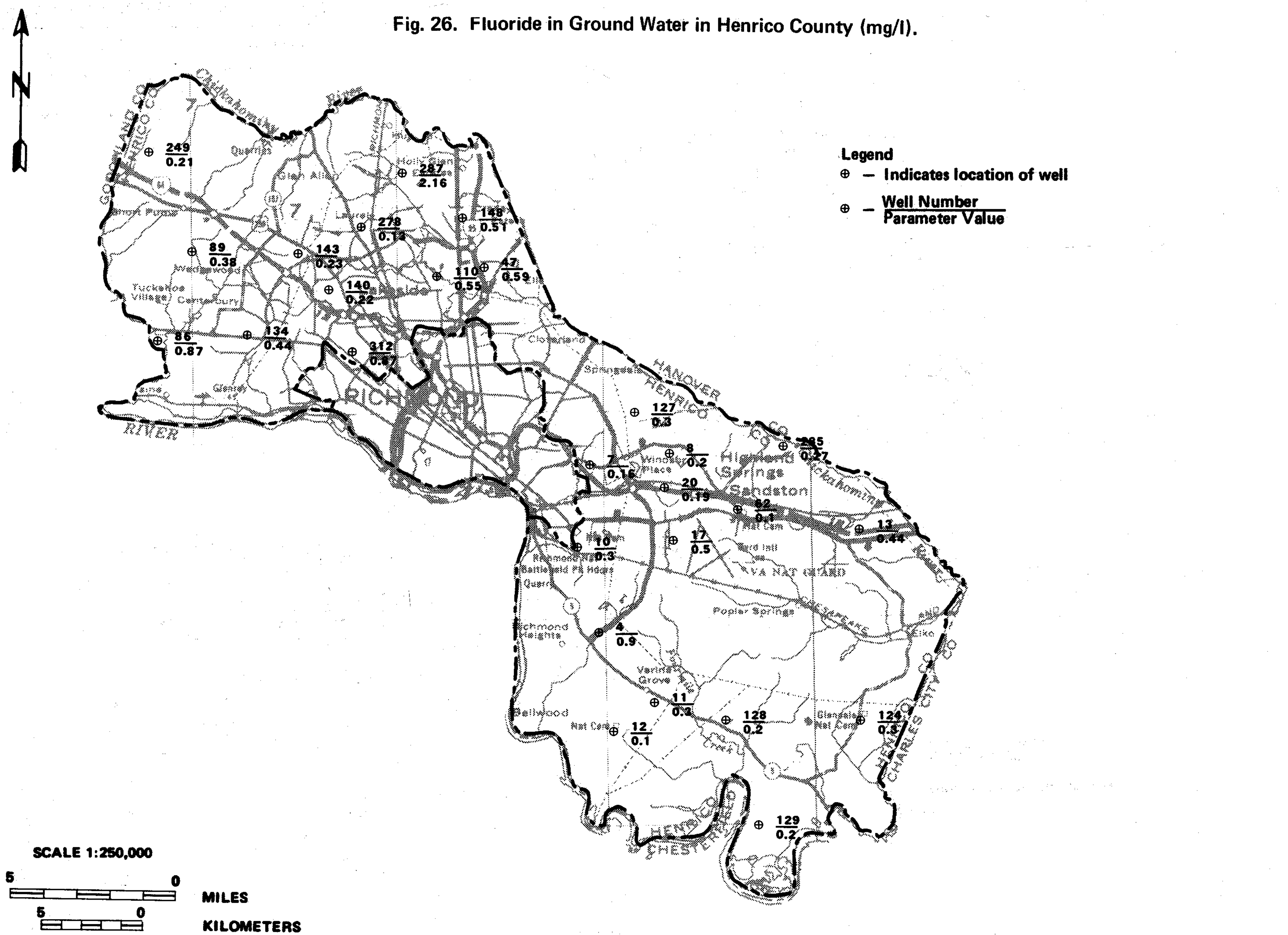
Fluoride in ground water usually is derived from the mineral fluorite (CaF_2) associated as a later-hydrothermal mineral in cavities and joints

Fig. 25. Chloride in Ground Water in Henrico County (mg/l).



SOURCE: State Water Control Board — P.R.O.

Fig. 26. Fluoride in Ground Water in Henrico County (mg/l).



SOURCE: State Water Control Board – P.R.O.

in granites and pegmatites. Some fluoride may come from micas and clays that have had (OH^-) groups replaced by (F^-). High fluoride concentrations can cause mottling of children's teeth. Mottling can occur at fluoride levels above 0.8 mg/l. Adults can tolerate levels of 3 to 4 mg/l without ill effects. Some fluoride is desirable in the prevention of tooth decay, with 1.0 mg/l chosen as the ideal concentration.

Fluoride values in Henrico County range from undetectable to 19.4 mg/l. Most of the high values are noted to come from wells in the Petersburg granite. Fluoride values in water from wells in the Patuxent Formation tend to be lower than in water from the Petersburg granite. Many of the lowest levels are found in shallow wells in the Quaternary regressive sands. Fluoride levels for all of the geologic formations in the county are given in Figure 26.

Nitrate (NO_3^-)

Nitrate can vary greatly in ground water, with little or no direct relationship to the surrounding geology or the aquifer. Concentrations of nitrates occur in the soil zone from nitrogen-fixing bacteria, fertilizer, manure, and plant debris. In spite of the potential for high concentrations, nitrates seldom appear in high concentrations in surface waters because they are constantly being utilized by plants. However, once nitrates migrate underground into drinking water supplies, many problems may result.

Nitrate concentrations greater than 45 mg/l may cause a toxic effect called "cyanosis" or "blue baby" in some infants. Cyanosis does not occur in older children and adults, but high concentrations may irritate the bladder and gastro-intestinal tract. A maximum value of 45 mg/l nitrate (NO_3^-) or 10 mg/l nitrogen (N) is the healthful limit determined by the State Health Department.

Nitrate concentrations in Henrico County vary from a high of 68.7 mg/l to undetectable levels. A few wells in the county are noted to have excessive concentrations. These wells tend to be shallow and the high values may be reflecting well construction problems. When high nitrate concentrations are found in ground water, it has been the experience of local health officials that the problem is due to the infiltration of fertilizers and manure into the ground water via a faulty well. This may be due to poor well design and well grouting or simply to settlement of the well casing after construction. It is particularly important that shallow wells be grouted sufficiently to prevent contaminants from nitrogen laden soil from entering the well.

Conclusions

Ground water quality in Henrico County is generally quite good. Several areas have unusually high values of certain substances but these concentrations are rarely a health hazard and usually are caused by the chemical composition of the subsurface aquifers.

The quality of all ground water must be maintained at its naturally-high standard. Ground water pollution is usually impossible to clean up and, therefore, prevention of pollution is the only viable recourse. The ground water quality information presented here should be utilized by the public not only to avoid areas of poor quality ground water, but also to familiarize the public with various kinds of natural and man-made contaminants affecting our fragile ground water resources.

CHAPTER VI

GROUND WATER RECHARGE & STORAGE

General

As partially discussed in the chapter on hydrogeology, ground water recharge to an aquifer is dependent upon precipitation, temperature, humidity, surface area of aquifer exposed to infiltration, vegetation, topography, soils, rock type, and overlying geology. The infiltration of precipitation depends on the porosity and permeability of the soil and the geologic formation. Generally, recharge rates are rapid in highly-fractured rock and permeable sand and gravel, and very slow in unfractured rock and less-permeable clay and silt.

The frequency and intensity of precipitation is a major factor in aquifer recharge. A large amount of precipitation is important for recharge; however, a light rain of long duration will allow more water to infiltrate than will a heavy downpour of short duration. There are several factors which limit the speed with which water percolates into the ground. Chief among these are friction between the water and the material through which it passes, grain size variations (see Figure 10), and forces of attraction between grains (Van der Waals forces). Due to these limiting factors, a heavy rainfall often supplies more water than can immediately percolate into the ground and much of the water is lost as runoff.

Two other factors which influence ground water recharge are vegetation and the depth and permeability of the soil. Vegetation plays a double role in that the root systems act to break up the soil, adding to the soil porosity and permeability. In areas of sparse soil cover roots will often act directly on the bedrock, enlarging fractures and causing pieces of the rock to break away. At the surface the vegetation acts as a physical barrier to runoff and adds to retention times. A thick soil (saprolite) zone provides more above rock storage than a thin soil (saprolite) zone and the permeability of the soil directly affects the amount of water which can pass through it to an underlying aquifer.

The ground water storage capabilities of the aquifers in Henrico County vary greatly. It is obvious that aquifers of greater extent, thickness, permeability and porosity generally have larger storage capacities than thin, localized, less porous aquifers.

Piedmont

The saprolite cover generally has adequate permeability for ground water recharge; however, increased intergranular friction on the infiltrating water, grain size variations within the saprolite, and Van der Waal's forces greatly impede the rate of ground water infiltration.

Storage capacities of the saprolite are dependent upon the volume of interconnected saprolite cover. Deep saprolite covers can store large volumes of ground water and, thus, can be very resistant to drought conditions.

It was pointed out before that ground water movement through the consolidated Piedmont bedrock is dependent upon the existence of fractures and joint networks within the bedrock. This is generally true for the Triassic rocks also. A large volume of ground water can pass through a fault zone and its interconnecting fractures with very little resistance from the intergranular friction and Van der Waal's forces which would be present in unconsolidated sediments. Ground water storage in the Piedmont bedrock is limited to the volume of space within the interconnected fractures and joints. These features can be of limited or vast extent. Their extent in any given area is usually unpredictable and; therefore, the ground water supply is unpredictable. Generally these zones are the last to dry up during droughts since the saprolite above supplies their water.

Coastal Plain

The near-surface aquifers in the Coastal Plain tend to recharge rapidly as precipitation falls. However, due to their thin, localized extent (small storage) and isolated (clay below) nature, they are susceptable to drought conditions. During droughts, ground water quality can become poorer due to ion concentration increases in the decreasing volume of water.

The artesian aquifers, both upper and principal, receive lateral recharge from the western outcrops of the formations themselves and vertical recharge from the highly porous (large storage), low permeability (low yield) clays of the upper, confining units. Lateral recharge is rapid once the ground water has entered the highly-permeable artesian aquifer. Vertical recharge is very slow, but the large areal extent of the artesian aquifers enables vast amounts of ground water to recharge vertically.

Artesian Aquifer Recharge (Patuxent Formation)

The procedure used to determine the recharge of an artesian aquifer is complicated and many factors must be considered. A generalized explanation of this procedure for the Patuxent Formation (principal artesian aquifer) in Henrico County will be developed below. The accuracy of these computations is dependent upon the accuracy of the data used. Since only gross estimates were used for most parameters, it is probable that the accuracy of these computations will increase as the data is refined in the future.

Infiltration of precipitation is considered to be the dominant source of ground water recharge. Total recharge into an artesian aquifer can be separated into its lateral and vertical components. Figure 27 shows the zones of lateral and vertical recharge in an artesian aquifer cross section.

Lateral recharge is supplied through the outcrop area of the formation. On the 1963 Geologic Map of Virginia the Patuxent outcrop covers approximately 32.25 square kilometers (347 million square feet). Rainfall in Henrico County averages 1.12 meters (3.68 feet) per year. It is estimated that 80% of the precipitation goes to runoff, vegetation and evaporation while the remaining 20% recharges the ground water supply. Twenty percent of a quantity of water 1.12 meters (3.68 feet) deep encompassing 32.25 square kilometers (347 million square feet) is equivalent to 7.23 billion liters (1.9 billion gallons) of water infiltrating the outcrop each year. At the outcrop much of this infiltrated water is water table (unconfined aquifer) water; however, a great portion of this water is available then to enter the confined portion of the aquifer (vertical recharge zone) by lateral recharge. The outcrop-recharge water is migrating constantly down dip into the confined portion of the aquifer to the east. This migration (lateral recharge) and its rate are restricted by the volume of water already in the confined aquifer, the friction and physical forces associated with water movement through intergranular spaces and the physical characteristics of the aquifer, such as thinning, which tend to retard water movement. Theoretically, however, a maximum of 7.23 billion liters (1.9 billion gallons) per year is available for lateral recharge.

The vertical recharge zone encompasses the entire surface area of the aquifer which is overlain by other units. The extent of the surface for the Patuxent Formation in Henrico County and Richmond north of the James River is approximately 373 square kilometers (144 square miles). Using the method above to calculate precipitation and percentage of infiltration, 83+ billion liters (22+ billion gallons) of water infiltrate into the vertical recharge zone. Because the tested hydraulic conductivity values for the confining units above the Patuxent formation are low, it is probable that no more than 1% of the water available for deep infiltration actually enters the Patuxent aquifer by vertical recharge each year. Thus, the total maximum recharge to the Patuxent would be about 8.06 billion liters (2.13 billion gallons) annually. The actual recharge is probably somewhat less due to blockage by water already in the aquifer.

Artesian Aquifer Storage (Patuxent Formation)

In order to estimate the total storage capacity of the Patuxent Formation, it was necessary to interpret thickness data contained in Brown's report (1972). A volume of 22.7 billion cubic meters (803 billion cubic feet) was calculated from this data. It is estimated that 35% of the formation volume is pore space capable of containing water. Thus, the total estimated ground water storage of the Patuxent

Formation in Henrico County is 7.96 trillion liters (2.1 trillion gallons) of water. Since only 6% of this total volume is believed recoverable, total ground water available from the Patuxent is 476.91 hundred billion liters (126 hundred billion gallons).

If the perpetual preservation of the aquifer is sought, withdrawals of ground water should not exceed the available recharge. Up to a point, increases in withdrawal will cause a proportional increase in recharge by reducing the blocking effect of water already in the aquifer. However, the physical forces, such as friction, which act upon water moving through the aquifer will establish a maximum rate at which recharge water can move through the aquifer. When water is withdrawn from the aquifer at a rate higher than the maximum recharge rate, depletion of the aquifer will result.

Conclusions

Ground water supplies in the Peidmont are generally sufficient for domestic and low demand purposes; however, large sustained yields are difficult to obtain.

While the water in the Patuxent Formation can undoubtedly be exploited further, it must be done in a manner which takes into account the amount of water available for recharge and the needs of those counties to the east which also tap this aquifer.

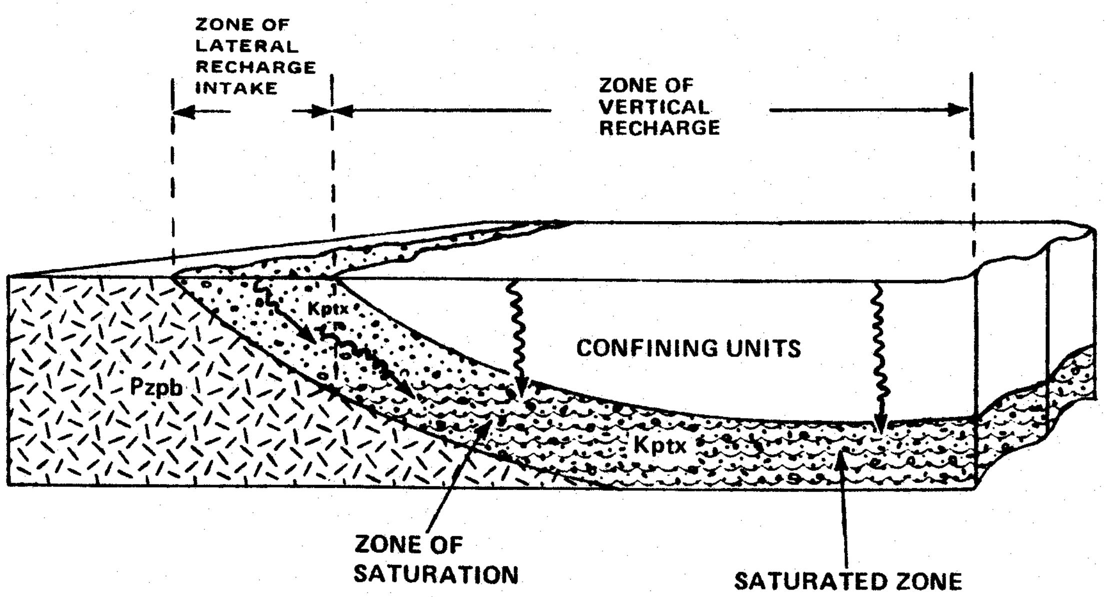


Fig. 27. A Schematic Showing a Subsurface Cross-Section of the Patuxent Formation and Zones of Lateral and Vertical Recharge.

SOURCE: STATE WATER CONTROL BOARD – PRO

CHAPTER VII

GROUND WATER DEVELOPMENT

General

Further development of the ground water resource in Henrico County is limited by ground water availability, well construction and operation costs, and the amount of water use. The availability of ground water has been discussed in the hydrogeology section of this report. The cost of well construction varies with well depth, geology, and location. The intended use of the ground water will dictate the yield and quality of water desired from the well.

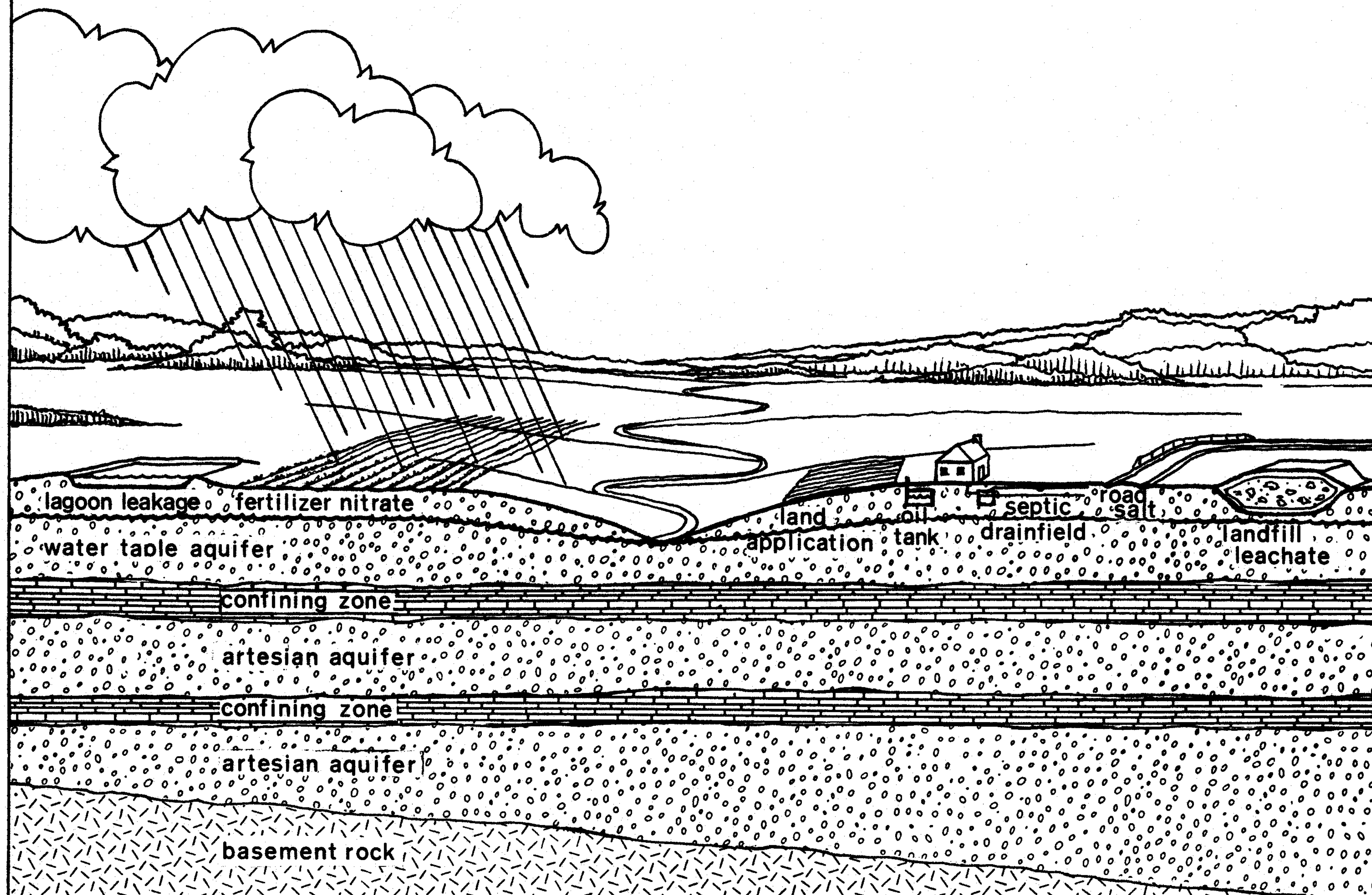
Well Construction

Many wells in the Piedmont section of the county, as well as in the Coastal Plain section, are shallow, bored wells which tap water supplies less than 100 feet deep. These wells are commonly 24 to 36 inches in diameter and are lined with concrete casing. When properly constructed they provide an adequate supply of water for most domestic and low demand purposes. Bored wells are generally less expensive than drilled wells and take less time to construct. This makes them an attractive option to many homeowners; however, there are disadvantages. Shallow wells are often a subject of concern from a health standpoint. Many of these wells become contaminated due to poor location, lack of grouting, separation in the well casing and failure of the well cap. Shallow wells are particularly vulnerable to contamination from failing septic systems. Contamination of one well can spread to other wells tapping the same shallow aquifer. Some counties have adopted regulations to ensure that shallow, bored wells are properly constructed.

Deep wells in the Piedmont are usually six inches in diameter although four and eight inch diameter wells are not uncommon. These wells attempt to tap ground water stored in the fractures of the bedrock below the saprolite. Steel casing is put in the well bore from the ground surface into the top of the bedrock to seal off the saprolite zone and prevent the sides of the hole from caving-in. The portion of the drilled hole that extends into bedrock will normally stay open. However, if a particularly extensive fracture zone is encountered before water is reached, some caving-in may occur. In this instance, the casing may be extended to seal off the portion of rock where the collapse is occurring.

Deep wells in the Coastal Plain are similar but differ in that the well must have side-wall support throughout its depth and screens must be placed alongside the water zones to keep sand out of the well and pump. Gravel is often placed around the outside of the screens to prevent fine particles in the aquifer from contacting the screens and clogging them. Both Piedmont and Coastal Plain wells should be grouted to prevent surface contamination from entering the well.

Fig. 28. Typical Ground Water Contamination Sources.



Ground Water Use

Ground water in Henrico County is used for domestic, industrial, commercial, agricultural, and public supply purposes.

Domestic use includes both individual household wells and the public supply wells of the many subdivisions in the county. The majority of wells in the State Water Control Board files for Henrico County are wells which were drilled to supply subdivisions. There are also relatively shallow wells bored to serve a single house. While these bored wells do not represent a majority of the records in the State Water Control Board files, their vast popularity is readily apparent to anyone driving through the county observing water wells.

Industrial ground water users include the General Baking Company, Valley Plating Company and U. S. Tobacco Company.

Public use wells include those used for schools, highway rest areas, public offices and parks. Schools are the largest users in this category.

Recently, rising energy costs have spurred an interest in the use of ground water source heat pumps. These devices make use of the temperature differences between ground water and prevailing atmospheric temperature in order to heat or cool buildings. Widespread use of such systems may place a serious demand on the ground water supply of the county, as well as create a serious potential for ground water contamination. The State Water Control Board is presently formulating regulations to provide for the effective use and management of these systems.

Future Development

The Henrico County Department of Public Utilities estimates that 4.805 million liters (1.3 million gallons) of ground water is pumped each day for use in public water supply systems owned by the county. Additional water is purchased from the City of Richmond. Public use of ground water is expected to double within the next five to ten years.

In addition to the increased demand on ground water resources caused by more extensive use of ground water source heat pumps, an increase in demand on ground water use for normal domestic purposes may be expected. Health Department officials report that new subdivisions where city water is not available are relying on individual shallow wells for each lot. The 1975 county land use map shows large areas of the eastern and western portions of the county set aside for low density residential development. As the use plan allows 0 to 4 units per acre, individual shallow wells are expected to remain the most prevalent source of domestic water for these areas.

APPENDIX I

The Groundwater Act of 1973 was passed by the Virginia Legislature to ensure the proper management and protection of Virginia's ground water resources. In order to accomplish this, provisions have been made in the law to obtain certain information from ground water users. This information is gathered through the use of the Water Well Completion Report, Ground Water Pumpage and Use Report, and the Application and Report, Abandonment of Water Well.

Water Well Completion Report - Form GW-2

The Water Well Completion Report provides an accurate, permanent, record of a water well. Included on the form is information concerning the location and construction of the well, the geologic features encountered, the yield, and the location of water zones. These forms are utilized by geologists with the State Water Control Board, the Virginia Division of Mineral Resources, the U.S. Geological Survey and various public and private groups and individuals. The data is used to make geologic maps, county ground water reports, ground water availability studies, and as an aid in well siting. Additionally, the reports are invaluable in the investigation of ground water and water well pollution problems. As it is often impossible to obtain this information years after a well has been drilled, it is in the best interests of the well owner to insist that the well contractor provide the State Water Control Board with a properly completed Water Well Completion Report.

Form GW-2
1978-10,000

COMMONWEALTH OF VIRGINIA
WATER WELL COMPLETION REPORT
• BWCM No. ______________

(Certification of Completion/County Permit)

State Water Control Board
P. O. Box 11143
2111 North Hamilton St.
Richmond, Va. 23230

SWCB Permit ______
County Permit ______

Certification of inspecting official:
This well does _____ does not _____
meet code/low requirements.
S. ______
Date ______

For Office Use

County/City ______________________

County/City Stamp

• Virginia Plane Coordinates
______ N
______ E
Latitude & Longitude
______ N
______ W
• Topo. Map No. ______
• Elevation ______ ft.
• Formation ______
• Lithology ______
• River Basin ______
• Province ______
• Type Logs ______
• Cuttings ______
• Water Analysis ______
• Aquifer Test ______

• Owner ______
• Well Designation or Number ______
Address ______
Phone ______

• Drilling Contractor ______
Address ______
Phone ______

Tax Map I.D. No. ______
Subdivision ______
Section ______
Block ______
Lot ______
Class Well: I ______, IIA ______,
IIB ______, IIIA ______, IIIB ______
IIIC ______ IIID ______ IIIE ______

WELL LOCATION: ______ (feet/miles ______ direction) of ______
and ______ feet/miles ______ (direction) of ______
(If possible please include map showing location marked)

Date started ______ • Date completed ______ Type rig ______

1. WELL DATA: New ____ Reworked ______ Deepened ______
• Total depth ______ ft.
• Depth to bedrock ______ ft.
• Hole size (Also include reamed zones)
• ______ inches from ______ to ______ ft.
• ______ inches from ______ to ______ ft.
• ______ inches from ______ to ______ ft.
• Casing size (I.D.) and material
• ______ inches from ______ to ______ ft.
Material ______
Wt. per foot ______ or wall thickness ______ in.
• ______ inches from ______ to ______ ft.
Material ______
Wt. per foot ______ or wall thickness ______ in.
• ______ inches from ______ to ______ ft.
Material ______
Wt. per foot ______ or wall thickness ______ in.
• Screen size and mesh for each zone (where applicable)
• ______ inches from ______ to ______ ft.
• Mesh size ______ Type ______
• ______ inches from ______ to ______ ft.
• Mesh size ______ Type ______
• ______ inches from ______ to ______ ft.
• Mesh size ______ Type ______
• ______ inches from ______ to ______ ft.
• Mesh size ______ Type ______
• Gravel pack
• From ______ to ______ ft.
• From ______ to ______ ft.
• Grout
• From ______ to ______ ft., Type ______
• From ______ to ______ ft., Type ______

2. WATER DATA • Water temperature ______ °F
• Static water level (unpumped level measured) ______ ft.
• Stabilized measured pumping water level ______ ft.
• Stabilized yield ______ gpm after ______ hours
Natural Flow: Yes ____ No ____, flow rate ______ g pm
Comment on quality ______

3. WATER ZONES: From ______ To ______
From ______ To ______. From ______ To ______
From ______ To ______. From ______ To ______

4. USE DATA:
Type of use: Drinking ______, Livestock Watering ______,
Irrigation ______ Food processing ______, Household ______,
Manufacturing ______, Fire safety ___, Cleaning ______,
Recreation ______, Aesthetic ______, Cooling or heating ______,
Injection ______, Other ______
• Type of facility: Domestic ______, Public water supply ______,
Public institution ______, Farm ______, Industry ______,
Commercial ______, Other ______

5. PUMP DATA: Type ______ • Rated H.P. ______,
• Intake depth ______ • Capacity ______ at ______ head

6. WELLHEAD: Type well seal ______
Pressure tank ______ gal., Loc. ______
Sample tap ______, Measurement port ______
Well vent ______, Pressure relief valve ______
Gate valve ______, Check valve (when required) ______
Electrical disconnect switch on power supply ______

7. DISINFECTION: Well disinfected ______ yes ______ no
Date ______, Disinfectant used ______
Amount ______, Hours used ______

8. ABANDONMENT (where applicable) • yes ______ no ______
Casing pulled yes ____ no ____ not applicable ______
Plugging grout From ______ to ______ material ______

OVER

Owner ______________________________ BWCM No. __________

9. State law requires submitting to the Virginia State Water Control Board information about groundwater and wells for every well made in the State intended for water, or any other non-exempt well. This information must be submitted whether the well is completed, on standby, or abandoned. Information required includes: an accurately and completely prepared water well completion report, full data from any aquifer pumping tests, drill cuttings taken at ten foot intervals (unless exemption is secured), the results of any chemical analyses, and copies of any geophysical logs. Quarterly pumpage and use reports are required from owners of public supply and industrial wells. County or State permits to drill may be required in some parts of the state. Some counties require submission of a water well completion report. The Virginia State Health Department requires a water well completion report for public supply wells.

10. DRILLERS LOG (use additional Sheets if necessary)				11.	12. DIAGRAM OF WELL CONSTRUCTION (with dimensions)
DEPTH (feet)		TYPE OF ROCK OR SOIL	REMARKS	Drilling	
From	To	(color, material, fossils, hardness, etc.)	(water, caving, cavities, broken, core, shot, (etc.)	Time (Min.)	

13. Well lot dedicated? ______; Size ______ ft. X ______ ft.; Well house? ______
Distance to nearest pollutant source ______ ft., Type ______
Distance to nearest property line ______ ft., Building ______ ft.

14. WATER SERVICE PIPE: Checked under ______ p.s.i. for ______ minutes. Pipe size ______ inches, Material ______
Installer ______
Date ______

15. I certify that the information contained herein is true and correct and that this well and/or system has been installed and constructed in accordance with the requirements for well construction as specified in compliance with appropriate county or independent city ordinances and the laws and rules of the Commonwealth of Virginia.

Signature ______________________ (Seal), Date ______
(Well driller or authorized person)
License No. ______

State Water Control Board Regional Offices

Valley Reg. Off.
116 North Main Street
P. O. Box 268
Bridgewater, Va. 22812
703-828-2595

Southwest Reg. Off.
408 East Main Street
P. O. Box 476
Abingdon, Va. 24210
703-628-5183

West Central Reg. Off.
Executive Park
5312 Peters Creek Road
Roanoke, Va. 24019
703-982-7432

Piedmont Reg. Off.
4010 West Broad Street
P. O. Box 6616
Richmond, Va. 23230
804-257-1006

Tidewater Reg. Off.
287 Pembroke Office Park
Suite 310 Pembroke No. 2
Va. Beach, Va. 23462
804-499-8742

Northern Virginia Reg. Off.
5515 Cherokee Avenue
Suite 404
Alexandria, Va. 22312
703-750-9111

Application and Report, Abandonment of Water Well - Form GW-5

The GW-5 is filed with the State Water Control Board when a water well is to be abandoned. This provides a record that the well is no longer in service so that it will no longer be included in calculations of ground water withdrawal rates. The form is also a certification that the well has been properly abandoned. Quite often a well which is no longer in use is used for the disposal of trash or left open to contamination by vandalism. Unless an abandoned well is properly sealed by the owner it is a direct avenue through which pollutants may enter an aquifer and contaminate surrounding wells.

FORM GW-5
8/74 1000

COMMONWEALTH OF VIRGINIA
STATE WATER CONTROL BOARD
P. O. Box 11143, 2111 North Hamilton Street
Richmond, Virginia 23230
Phone (804) 770-1411

APPLICATION AND REPORT
ABANDONMENT OF WATER WELL
(For use in all groundwater areas)

(Card 28)

I. APPLICATION

OWNER: ______________________________
1-20

ADDRESS: ______________________________
____
21-60

WELL LOCATION: ______________________________

Owner herewith applies to abandon (check which) temporarily ( )61 or permanently ( )62 his water well identified by:

1. Application and Permit to Construct a Water Well number ________,
63-66

2. Certificate of Groundwater Right number ________.
67-70

If (1) and (2) above are not applicable, complete the following statement:

MAXIMUM DAILY WITHDRAWAL OF GROUNDWATER IS ________ GALLONS.
71-78

(Card 29)

USE TO WHICH GROUNDWATER WAS APPLIED: ______________________________.

TOTAL DEPTH OF WELL: ____________ FEET.
1-4

EXACT DATE ON WHICH ABANDONMENT WILL BE DONE: ______________.
5-10

NOTE: 1. Applicant shall furnish a sketch of water well and indicate proposed procedures and materials to be used in abandonment.

2. Abandonment shall conform with IIIF, "Standards for Water Wells", published by the Board.

APPLICATION APPROVED BY: ______________________________
11-40

DATE: ______________________________
41-46

Ground Water Pumpage and Use Report - Form GW-6

Any person using an industrial or public supply water well must provide the State Water Control Board with a GW-6 for each quarter of the year. The reports are due on or before the fifth day of January, April, July and October for the preceding three months use. This information is used in conjunction with the GW-2 to monitor ground water withdrawals from different aquifers. In drought years it is particularly important that these reports are accurately completed and submitted so that critical water shortages may be anticipated and possibly avoided.

WSE Form W-2 (3-80)
SWCB Form GW-6 (3-80)

COMMONWEALTH OF VIRGINIA
GROUND WATER PUMPAGE AND USE REPORT

State Department of Health and State Water Control Board

Year ____
Month ____
Quarter 1 2 3 4 (Circle One)
County/City ____

Water Source:

____ Well(s)

____ Spring(s)

____ Well(s) and Spring(s)

Public. Send copy of report to Regional State Water Control Board Office and Regional State Health Department Office
Industrial. Send copy of report to Regional State Water Control Board Office
Other. Send copy of report to Regional State Water Control Board Office

Name of Waterworks ____

Owner ____
Address ____
____ Phone ____

Name of Operator ____
Position/Title ____
Signature ____ Date ____
Population Served (Public) ____
No. of Connections (Public) ____
Operation Permit Number (Public) ____

Type of Use: Public+ ____ Industrial ____ Other (specify ____

If measurements are for a single-meter field reading, list wells included in field

SWCB No. ____ Owner No. ____ SWCB No. ____ Owner No. ____
SWCB No. ____ Owner No. ____ SWCB No. ____ Owner No. ____
SWCB No. ____ Owner No. ____ SWCB No. ____ Owner No. ____

Meter readings are in ____ (gallons, 1000's of gallons, cubic feet, etc.)

SWCB No. Owner No.

Date	Meter Reading*	Gallons Used	Water Level**** Static**	Water Level**** Pumping***
End of Last Month				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

Note: If system is unmetered, estimate pumpage in boxes in lower right-hand corner.

Date	Meter Reading*	Gallons Used	Water Level**** Static**	Water Level**** Pumping***
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				

Total Gallons During Month		Total Gallons During Quarter	
Total Operating Days this Month		Total Operating Days this Quarter	
Daily Average During Month		Daily Average During Quarter	

* Read meter same time each day (preferably end of day)
**If taken, read at end of non-pumping period
***If taken, read at end of heavy-pumping period
****If taken in one well in a field, specify which well ____
\+ All privately or publically-owned public water supply systems with Health Department permits.

APPENDIX II

Ground Water Quality Standards and Criteria

Ground Water Quality Standards and Criteria

Amendment to Water Quality Standards
Virginia State Water Control Board

Effective: August 1, 1977

Pursuant to Section 62.1-44.15(3) of the State Water Control Law (Chapter 3.1 of Title 62.1, Code of Virginia, 1950, as amended)

5.00 Ground Water Criteria and Standards

Ground water quality standards will apply statewide, and will apply to all ground water occurring at and below the uppermost seasonal limits of the water table. In order to prevent the entry of pollutants into ground water occurring in any aquifer, a soil zone or alternate protective measure or device sufficient to preserve and protect present and anticipated uses of ground water shall be maintained at all times. Zones for mixing wastes with ground water may be allowed upon request, shall be determined on a case-by-case basis, and shall be kept as small as possible.

It is recognized that natural ground water quality varies statewide. Four physiographic provinces have been determined for application of standards, namely the Coastal Plain, Piedmont and Blue Ridge, Valley and Ridge, and Cumberland Plateau. (See Plate 28)

If the concentration of any constituent in ground water is less than the limit set forth by ground water standards, the natural quality for that constituent shall be maintained; natural quality shall also be maintained for all constituents, including temperature, not set forth in any ground water standards. If the concentration of any constituent in ground water exceeds the standard for that constituent, no addition of that constituent to the naturally occurring concentration shall be made. Variance to this policy will not be made unless it has been affirmatively demonstrated that a change is justifiable to provide necessary economic or social development, that the necessary degree of waste treatment cannot be economically or socially justified, and that the present and anticipated uses of such water will be preserved and protected.

TABLE VI

GROUND WATER QUALITY STANDARDS
(See Fig. 28)

Statewide Standards

Constituent	Concentration	
Arsenic	0.05	mg/1
Barium	1.0	mg/1
Cadmium	0.4	ug/1
Chromium	0.05	mg/1
Copper	1.0	mg/1
Cyanide	5.0	ug/1
Foaming Agents as Methylene Blue Active Substances	0.05	mg/1
Lead	0.05	mg/1
Mercury	0.05	ug/1
Petroleum Hydrocarbons	1.0	mg/1
Phenols	0.001	mg/1
Selenium	0.01	mg/1
Silver	0.00	
Zinc	0.05	mg/1
Chlorinated Hydrocarbon Insecticides		
Aldrin/Dieldrin	0.003	ug/1
Chlordane	0.01	ug/1
DDT	0.001	ug/1
Endrin	0.004	ug/1
Heptachlor	0.001	ug/1
Heptachlor Epoxide	0.001	ug/1
Kepone	0.00	
Lindane	0.01	ug/1
Methoxychlor	0.03	ug/1
Mirex	0.00	
Toxaphene	0.00	
Chlorophenoxy Herbicides		
2,4-D	0.1	mg/1
2,4,5-TP	0.01	mg/1
Radioactivity		
Gross Beta	1000.0	pc/1
Radium 226	3.0	pc/1
Strontium 90	10.0	pc/1

Constituent	Concentration in the Coastal Plain	Piedmont & Blue Ridge	Valley & Ridge	Cumberland Plateau
Ammonia Nitrogen	0.025	0.025	0.025	0.025 mg/1
Nitrate Nitrogen	5.0	5.0	5.0	0.5 mg/1
Nitrite Nitrogen	0.025	0.025	0.025	0.025 mg/1
pH	6.5-9.0	5.5-8.5	6.0-9.0	5.0-8.5

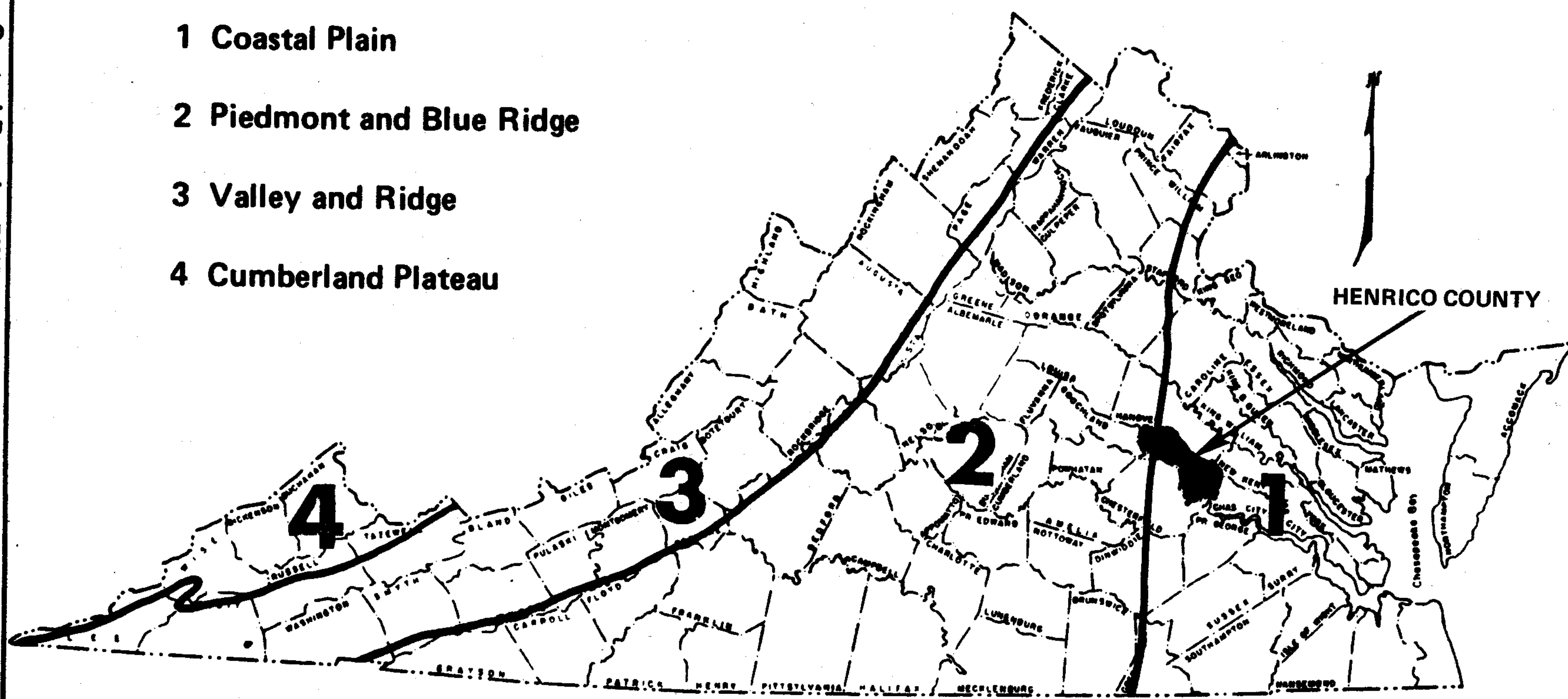
PHYSIOGRAPHIC PROVINCE BOUNDARIES FOR GROUND WATER QUALITY STANDARDS

1 Coastal Plain

2 Piedmont and Blue Ridge

3 Valley and Ridge

4 Cumberland Plateau



Source: Virginia State Water Control Board — BWCM

PLATE NO. 28

TABLE VII

GROUND WATER QUALITY CRITERIA
(See Fig. 28)

Constituent	Concentration in the Coastal Plain	Piedmont & Blue Ridge	Valley & Ridge	Cumberland Plateau
Alkalinity	30-500	10-200	30-500	30-200 mg/1
Chloride	50*	25	25	25 mg/1
Color	15	15	15	15 color units
Fluoride	1.4**	1.4	1.4	1.4 mg/1
Hardness	120	120	300	180 mg/1
Iron	0.3	0.3	0.3	0.01 - 10 mg/1
Manganese	0.05	0.05	0.05	0.01 - 0.5 mg/1
Sodium	100*	25	25	100 mg/1
Sulfate	50	25	100	150 mg/1
Total Dissolved Solids	1000	250	500	500 mg/1
Total Organic Carbon	10	10	10	10 mg/1

*It is recognized that naturally occurring concentrations will exceed this limit in the eastern part of the Coastal Plain, especially toward the shoreline and with increased depth.

**Except within the Cretaceous aquifer: concentration up to 5 mg/1 and higher

TABLE VIII

MAJOR CHEMICAL CONSTITUENTS IN GROUND WATER

Constituent	Maximum Recommended Concentration (mg/l)*	Remarks
Calcium	200	Seldom a health concern; may be a disadvantage in washing, laundry, bathing; encrustations on utensils
Chloride	**250 (Aesthetics)	Taste is a major criterion; generally not harmful unless in very high concentrations, but may be injurious to sufferers of heart and kidney diseases; sea water is 19,000 mg/l
Fluoride	**1.8 (Health)	Presence of about 1.0 mg/l may be more beneficial than detrimental; concentrations less than 0.9 to 1.0 mg/l will seldom cause mottled enamel in children's teeth; extreme doses (2.5 to 4 grams) may cause death
Hardness (as $CaCO_3$)	0-60 Soft 61-120 Mod. Hard 121-180 Hard 181+ Very Hard	Hard waters have had no demonstrable harmful effects upon the health of consumers; major detrimental effect is economic--values above 100 mg/l become increasingly inconvenient; wastes soap and causes utensil encrustation
Iron	**0.3 (Aesthetics)	Essential to nutrition and not detrimental to health unless in concentrations of several milligrams; main problems are bad taste, staining and discoloration of laundry and porcelain fixtures
Magnesium	150	Not a health hazard because taste becomes extremely unpleasant before toxic concentrations reached; may have laxative effect on new users
Manganese	**0.05 (Aesthetics)	Essential to nutrition but may be toxic in high concentrations; taste becomes problem before toxic concentrations reached; undesirable because it causes bad taste, deposits on cooked food, stains and discolors laundry and plumbing fixtures
Nitrate	**10 as N (Health)	May be extremely poisonous in high concentrations; may cause disease in infants ("blue baby"); irritates bladder and gastrointestinal tract, may cause diarrhea
pH	**6.5-8.5 (Aesthetics)	Indicates whether solution will act as an acid or base; water acquires "sour" taste below 4; high values favor corrosion control; efficiency of chlorination severely reduced when pH above 7
Potassium	1000-2000	May act as a laxative in excessive quantities
Sodium	100	May be harmful to sufferers of cardiac, circulatory, or kidney disease; concentrations as low as 200 mg/l may be injurious
Solids (Total Dissolved)	**500 (Aesthetics)	Not a health hazard above 500 mg/l, but may impart disagreeable taste, corrode pipes; general indicator of the amount of minerals in water
Specific Conductivity	1000	An indicator of the amount of dissolved solids in water; high concentrations can cause corrosion of iron and steel
Sulfate	**250 (aesthetics)	Above 250 mg/l may act as laxative on new users; may impart foul taste and odor

*Recommended concentrations based on current literature; pH measured in units, Conductivity in micromhos

**Actual limits established by the Virginia Department of Health; parentheses () indicate basis for limit

Source: Modified after McKee and Wolf (1963), Hem (1970), Virginia Department of Health (1977)

APPENDIX III

Planning Guide for Water Use

TABLE IX

PLANNING GUIDE FOR WATER USE

Types of Establishments	Gallons per day
Airports (per passenger)	3-5
Apartments, multiple family (per resident)	60
Bath houses (per bather)	10
Camps:	
Construction, semipermanent (per worker)	50
Day with no meals served (per camper)	15
Luxury (per camper)	100-150
Resorts, day and night, with limited plumbing (per camper)	50
Tourist with central bath and toilet facilities (per person)	35
Cottages with seasonal occupancy (per resident)	50
Courts, tourist with individual bath units (per person)	50
Clubs:	
Country (per resident member)	100
Country (per nonresident member present)	25
Dwellings:	
Boardinghouses (per boarder)	50
Additional kitchen requirements for nonresident boarders	10
Luxury (per person)	100-150
Multiple-family apartments (per resident)	40
Rooming houses (per resident)	60
Single family (per resident)	50-75
Estates (per resident)	100-150
Factories (gallons per person per shift)	15-35
Highway rest area (per person)	5
Hotels with private baths (2 persons per room)	60
Hotels without private baths (per person)	50
Institutions other than hospitals (per person)	75-125
Hospitals (per bed)	250-400
Laundries, self-serviced (gallons per washing, i.e., per customer)	50
Livestock (per animal):	
Cattle (drinking)	12
Dairy (drinking and servicing)	35
Goat (drinking)	2
Hog (drinking)	4
Horse (drinking)	12
Mule (drinking)	12
Sheep (drinking)	2
Steer (drinking)	12
Motels with bath, toilet, and kitchen facilities (per bed space)	50
With bed and toilet (per bed space)	40
Parks:	
Overnight with flush toilets (per camper)	25
Trailers with individual bath units, no sewer connection (per trailer)	25
Trailers with individual baths, connected to sewer (per person)	50

Picnic:
  With bathhouses, showers, and flush toilets (per picnicker).......20
  With toilet facilities only (gallons per picnicker)..............10
Poultry:
  Chickens (per 100)...5-10
  Turkeys (per 100)..10-18
Restaurants with toilet facilities (per patron)..................7-10
  Without toilet facilities (per patron).........................2½-3
  With bars and cocktail lounge (additional quantity per person).....2
Schools:
  Boarding (per pupil)...75-100
  Day with cafeteria, gymnasiums, and showers (per pupil)...........25
  Day with cafeteria but no gymnasiums or showers (per pupil).......20
  Day without cafeteria, gymnasiums, or showers (per pupil).........15
Service stations (per vehicle).....................................10
Stores (per toilet room)...400
Swimming pools (per swimmer).......................................10
Theaters:
  Drive-in (per car space)..5
  Movie (per auditorium seat).......................................5
Workers:
  Construction (per person per shift)...............................50
  Day (school or offices per person per shift)......................15

Source: U.S. Environmental Protection Agency (1974)

APPENDIX IV

Summary of Water Well Data for Henrico County

SWCB NO.	OWNER	VA. PLANE COORD NORTH	EAST	DRILLER	YR COMP	ELEV	TOT DEPTH	SWL	PUMP LEVEL	ZONES OR SCREENS	YIELD	BED-ROCK	FORM-ATION	LITH-OLOGY	LOGS	TYPE
1	THE FLINTKOTE CO	430100	2335800	SYDNOR	59	160	285	147	175	0172 0182	50	265	PZPB	GR	DE	IND
										0230 0255						
2	FAIRFIELD WATER CORP	441700	2327300	SYDNOR	66	160	302	159	253		214	297	KPTX	SDG	DE	PWS
3	VARINA HIGH SCHOOL	420150	2328600	SYDNOR	61	142	266	89	129	0105 0120	6	247	KLP	SDA	DE	
										0123 0138						
4	VARINA HIGH SCHOOL	416700	2326100	SYDNOR	61	140	712	210	400	0698 0710	12	221	TRN	AS	DE	PWS
5	GEORGE STONEMAN JR	421800	2318400	SYDNOR	67	160	244	134	183	0193 0208	17		KPTX	SDG	DE	DOM
6	GLENWOOD GOLF COURSE	445500	2322300	SYDNOR	66	135	227	144	182	0176 0196	7	220	PZPB	GR	D	COM
										0216 0222						
7	HENRICO COUNTY	442600	2323700	SYDNOR	64	155	267					257	PZPB	GR	D	
8	SHU-LU CORP	445050	2336700	SYDNOR	66	160	314	157	227	0226 0236	73		KPTX	SDG	DE	IND
										0269 0289						
9	BAKER E S& VARINA H S	420600	2328500	SYDNOR	62	147	287	138			80		KPTX	SDG	E	
10	COMMONWEALTH SAND&GRA	429000	2323700	SYDNOR	64	155	296	125		0210 0230	137		KLP	SDA	DE	IND
										0240 0255						
11	VARINA ELEM SCHOOL	406400	2332350	SYDNOR	63	142	234	96	176		42		KPTX	SDG	DE	PUB
12	NAT PARK SERVICE	400050	2327550	SYDNOR	65	130	187	36		0075 0090	10		KPTX	SDG	E	PWS
										0117 0122						
13	HENRICO COUNTY #1	433100	2367650	SYDNOR	67	140	651	135	171	0370 0386	400	640	TRN	AS	D	PWS
										0435 0452						
										0462 0473						
										0475 0488						
										0433 0504						
14	FAIRFIELD WATER CORP	443000	2330500	SYDNOR	58	150	330						KPTX	SDG	E	PWS
15	HENRICO COUNTY	440400	2338400	MITCHELL	64	170	375	152	220		94		KLP	SDA	G	PWS
16	FAIRFIELD WATER CO #1	442300	2327600		57		297	102	211	0251 0267	145		KPTX	SDG		PWS
										0153 0173						
										0195 0205						
										0229 0234						
17	LEWIS GARDENS SER COR	432300	2336400	SYDNOR	67	160	290	150		0180 0210	43		KPTX	SDG	E	PWS
18	LEWIS GARDENS #3-A	432500	2336800	SYDNOR	63	160	278	153		0240 0245	85		KPTX	SDG	DE	PWS
										0254 0264						
										0268 0273						
19	HENRICO COUNTY SCHOOL	439100	2342000	MITCHELL	61	168	326	165	219	0248 0288	180		KPTX	SDG	D	PUB
20	HENRICO COUNTY	438800	2334100	SYDNOR	65	150	340	137	215	0263 0290	226		KPTX	SDG	D	PWS
										0290 0307						
										0311 0328						
21	COMMONWEALTH NAT GAS	388400	2325100		68		100									IND
22	SYDNOR	435500	2327500	SYDNOR	59	155	265				272		KPTX	SDG	DE	PWS
23	OBSERVATION WELL	463300	2274400			275	300				4		PZPB	IG		PUB
24	BESSIRE & CO	472300	2289200	MATHEWS	66	210	400	20	370		5	42	PZPB	IG	D	IND
25	HENRICO COUNTY	445200	2340000	SYDNOR			269	111	194	0247 0265	85			UN		PWS
26	HENRICO COUNTY	442900	2341300		35	150	306	133		0215 0306	161		KPTX	SDG		PWS
27	HENRICO CO DEPT CONST	401800	2335800	SYDNOR	77	130	250	99	119	0182 0192	50		KPTX	SDG	DE	PWS
										0198 0208						
										0220 0230						
28	HENRICO COUNTY	441000	2339950	MITCHELL	58	157	350	163	188	0243 0274	144		KPTX	SDG	D	PWS

V I R G I N I A   S T A T E   W A T E R   C O N T R O L   B O A R D

B U R E A U   O F   W A T E R   C O N T R O L   M A N A G E M E N T

DATE 06/12/80

SUMMARY OF WATER WELLDATA FOR HENRICO COUNTY

****

SWCB NO.	OWNER	VA. PLANE COORD NORTH	EAST	DRILLER	YR COMP	ELEV	TOT DEPTH	SWL	PUMP LEVEL	ZONES OR SCREENS	YIELD	BED-ROCK	FORM-ATION	LITH-OLOGY	LOGS	TYPE
29	HENRICO COUNTY #1	433920	2329200	SYDNOR	62	165	300						KPTX	SDG	D	PWS
30	HENRICO COUNTY #2	435700	2330500	MITCHELL	57	140	292	120	159	0213 0248			KPTX	SDG		PWS
31	HENRICO COUNTY	434250	2338000	SYDNOR	64	12	350	153	256	0215 0220	50		KLP	SDA	DE	PWS
										0228 0243						
										0280 0290						
										0305 0310						
32	HENRICO COUNTY	435200	2336400	MITCHELL	63	150	370	175	222	0190 0200	94		KLP	SDA	D G	PWS
										0200 0300						
33	HENRICO COUNTY	434950	2343850	SYDNOR	18	165	267			0241 0267	100		KPTX	SDG		PWS
34	HENRICO COUNTY	435450	2343600	SYDNOR	18	165	272	128	150	0222 0262	150		KPTX	SDG		PWS
35	HENRICO COUNTY	432200	2345275	MITCHELL	55	153	312	135	158		257		KPTX	SDG	D	PWS
36	HENRICO COUNTY	432175	2346820	MITCHELL	61	158	322	152	219	0237 0277	175		KPTX	SDG	D	PWS
37	HENRICO COUNTY	435100	2347900	MITCHELL	64	152	292	160	210		135		KLP	SDA	D G	PWS
38	L M KNIGHT	411109	2357022													
39	HENRICO COUNTY	434550	2333300	SYDNOR	61	160	300	138	147	0220 0260	112		KPTX	SDG	DE	PWS
40	HENRICO COUNTY	434000	2334950	SYDNOR	55	160	212	125	174	0175 0206	55		KPTX	SDG	D	
41	HENRICO COUNTY	434000	2334950	SYDNOR	60	160	340	154	213	0218 0238	28		KPTX	SDG	DE	PWS
										0249 0259						
42	HENRICO COUNTY	439450	2326250	MITCHELL	56	150	237	124	177	0206 0237	150		KPTX	SDG	D	PWS
43	SYDNOR, MAYFIELD SUB	457700	2291600				338				18		PZPB	GR		PWS
44	SYDNOR,MAYFIELD SUB#2	457600	2291600				230				14		PZPB	GR		PWS
45	HENRICO COUNTY	471000	2306150	SYDNOR	45	150	306	62	73		120		PZPB	GR		
46	HENRICO COUNTY	471150	2305850	SYDNOR	54	130	376	28	58		225		PZPB	GR		
47	HENRICO COUNTY	472800	2305000	SYDNOR	55	150	322	72	169		275		PZPB	GR		
48	HENRICO COUNTY	473900	2306850	SYDNOR	56	180	466	90	134		360		PZPB	GR		
49	HENRICO COUNTY	474300	2307400	SYDNOR	58	175	380	80	110		205		PZPB	GR		
50	HENRICO COUNTY			MITCHELL	55		330	146	185		120	286	PZPB	GR	D	PWS
51	N W CARRINGTON			SYDNOR	43		389	62	389		2	129	PZPB	GR		DOM
52	HENRICO COUNTY	472500	2284000	SYDNOR		265							PZPB	GR		PWS
53	HENRICO COUNTY			SYDNOR												PWS
54	SYDNOR	432700	2323500	SYDNOR		165	183	117					KPTX	SDG	D	PWS
55	SYDNOR, RIDGE CREST			SYDNOR									PZPB	GR		
56	SYDNOR, RIDGE CREST			SYDNOR			348						PZPB	GR		
57	SYDNOR,WOODLAWN FARMS	471900	2282450	SYDNOR		270							PZPB	GR		PWS
58	SYDNOR,WOODLAWN FARMS	473000	2282100	SYDNOR	55	270	257		116		31		PZPB	GR	D	PWS
59	SYDNOR,WESTWOOD #1	459750	2287400	SYDNOR	52	235	236	15			55		PZPB	GR	D	
60	B C COBB	434000	2327300	MITCHELL	47	155	290	120	142		110		KPTX	SDG	D	PWS
61	B C COBB	434700	2327350	MITCHELL	48	165	302	112	140		189		KPTX	SDG	D	PWS
62	HENRICO COUNTY	436800	2346900	SYDNOR	69	150	540	155	267	0304 0312	340		KPTX	SDG	DE	PWS
										0318 0360						
										0404 0456						
63	KELLY'S RESTAURANT	443800	2329600	SYDNOR	69	150	286	162	206	0252 0272	43		KPTX	SDG	DE	COM
64	BLUE CROSS & BLUE SHI	456650	2292700	SYDNOR	69	200	400	10	300		14	30	PZPB	GR	D	COM
65	HENRICO CO SCHOOLS	487300	2288950	MITCHELL	52	200	57	12	40		15	50	PZPB	GR	D	PUB
66	FRANKLIN A TRICE			MITCHELL	49		260	138	208	0197 0260	70			UN	D	

SWCB NO.	OWNER	VA. PLANE COORD NORTH	EAST	DRILLER	YR COMP	ELEV	TOT DEPTH	SWL	PUMP LEVEL	ZONES OR SCREENS	YIELD	BED-ROCK	FORM-ATION	LITH-OLOGY	LOGS	TYPE
67	VA DEPT OF HIGHWAYS			MITCHELL	58		290	30	65		30					PUB
68	HIGHLAND SPRINGS SCH	442860	2339850	MITCHELL	61	160	350	164	234		76		KPTX	SDG	D	PUB
69	FRANKLIN A TRICE			MITCHELL	49		267	135	216	0233 0267	90		KPTX	SDG	D	
70	FRANKLIN A TRICE			MITCHELL	49		262	142	200	0232 0262	30		KPTX	SDG	D	
71	AIR REDUCTION SALES	429800	2316900	SYDNOR	49	55	360	30	171	0258 0261	107	141	PZPB	GR	D	IND
										0338 0348						
72	HENRICO COUNTY			MITCHELL	49		268	131	180	0190 0217	92		PZPB	GR	D	PWS
73	AIRLINE TAVERN			MITCHELL	50		227	135	158		15		KPTX	SDG	D	COM
74	BAUGHAN BROTHERS INC	437200	2323500		56	90	20							SDG		
75	FRANKLIN A TRICE			MITCHELL	49		256	136	190	0178 0235	165		KPTX	SDG	D	
76	COMMONWEALTH OF VA	422200	2367150	SYDNOR	50	130	392	7	208	0239 0261	175		KPTX	SDG	D	PUB
77	GENERAL BAKING CO,FFV	451150	2297500	SYDNOR	49	205	697	11	241	0047 0049	18	43	PZPB	GR	D	IND
										0349 0359						
78	HENRICO CO SCHOOLS	406100	2332100	MITCHELL	50	138	213		164	0200 0212	30		KPTX	SDG	D	PUB
79	HENRICO COUNTY	442300	2341850	SPAIN	53	160	270	160	200	0223 0270	180		KPTX	SDG	D	PWS
80	HENRICO COUNTY	403550	2335200	SPAIN	55	140	173	98	138	0152 0173	40		KPTX	SDG	D	PWS
81	SHELL SERVICE STATION	474400	2287100	SYDNOR	68	230	122	10	122	0066 0069	17		PZPB	IG	G	COM
82	BESSIE MANEY	414936	2339799													
83	SYDNOR, PINE HEIGHTS	434150	2353950	SYDNOR		160	236	130		0205 0226			KPTX	SDG		PWS
84	RIGSBY CONST CO			GENTRY	52		400	40			125	87	PZPB	IG	D	
85	RIGSBY CONST CO			GENTRY			400	8			30	24	PZPB	IG	D	
86	SYDNOR, PAGEBROOK SUB	461300	2254000	THOMAS	70	140	297			0122 0147	3	18	PZPB	GR	D	PWS
87	MCDONALDS RESTAURANT	443650	2329300	SYDNOR	70	155	295	166	219	0252 0272	43		KPTX	SDG	D	COM
88	R T SCOTT			SYDNOR	70		320				1	13	PZPB	IG	D	
89	COLUMBIAN COMM CENTER	470200	2258400	MATHEWS	70	270	225	12	201	0068 0108	7	24	PZPB	GR	D	PUB
90	LOWER TUCKAHOE SER CO			WATER WEL	70		200				38	25	TRN	AS	D	PWS
91	C & P TELEPHONE CO	444250	2329300	ATLANTIC	70	155	300	163	355	0260 0300	56		KPTX	SDG	D	COM
92	FAIRFIELD WATER CO	440450	2329900	SYDNOR	71	135	310	152	212	0232 0262	201		KPTX	SDG	D	PWS
										0266 0276						
										0292 0297						
93	NABISCO INC	424400	2332850	ATLANTIC	72	155	345	60	228	0149 0159	12		KPTX	SDG	DE	IND
										0199 0209						
94	HENRICO COUNTY	475400	2265050	FELLS	56	215	119	107			40					PWS
95	HENRICO COUNTY	451000	2322000			170	307		250	0269 0307	45		PZPB	GR		PWS
96	VALLEY PLATING CO	457650	2314800			185	300						PZPB	GR		IND
97	HENRICO COUNTY	433200	2350600		49	155	460						KPTX	SDG		PWS
98	MASONIC HOME	440300	2325600		99	152	217	105		0190 0201			KPTX	SDG		PUB
99	MASONIC HOME	440200	2324650		28	152	252	110	170	0197 0218	125		KPTX	SDG		PUB
										0228 0252						
100	CONCRETE BUILDING UNI	429300	2323550		63	160	520			0200 0255			KPTX	SDG		IND
101	HENRICO COUNTY	434100	2354600	SYDNOR	72	160	610					606	TRN	AS	D	
102	BYRD AIRPORT													UN		
103	CANTERBURY SUB #3															
104	GINTER GARDENS												PZPB	GR		
105	HENRICO COUNTY			SYDNOR	47		270	135	200		100					PWS

****

SWCB NO.	OWNER	VA. PLANE COORD NORTH	EAST	DRILLER	YR COMP	ELEV	TOT DEPTH	SWL	PUMP LEVEL	ZONES OR SCREENS	YIELD	BED-ROCK	FORM-ATION	LITH-OLOGY	LOGS	TYPE
106	HENRICO COUNTY			SYDNOR	48		290	135	200		100					PWS
107	HEN.CO,HIGHLAND SPNGS	442860	2339550													
108	SYDNOR, KILDARE SUB			SYDNOR			275				30		PZPB	GR		PWS
109	LAKESIDE COUNTRY CLUB	471700	2299600			180							PZPB	GR		COM
110	LAKESIDE COUNTRY CLUB	471700	2299600			180	280	50	225		65		PZPB	GR		COM
111	HENRICO COUNTY															PWS
112	C M SPROUSE	397349	2364382			105										
113	A W ROBINSON	385961	2367520			35										
114	LITTLE OIL CO															COM
115	CHESTERFIELD CONST CO	395500	2321400	DOWDY	74	40	47	32					QS	SDG		DOM
116	INTER 95 REST AREA	488900	2303950	SYDNOR	66	135	350	26	290		13	35	PZPB	GR	D	PWS
117	INTER 95 REST AREA	489000	2303900	SYDNOR	66	135	300	18	263	0131 0186	2	45	PZPB	GR	D	PWS
118	OBSERVATION WELL #55	434250	2337800			155	297	152			75		KPTX	SDG		PUB
119	JOHN DEL CARDAYRE			SYDNOR	61		353	28	131		4	18	PZPB	IG	D	DOM
120	FORT HARRISON			SYDNOR	63		187	36		0075 0090				UN	E	PUB
										0117 0122						
121	W J LANKAM JR.			DOWDY	74		43	20								DOM
122	RICHMOND EQUIVEST INC	463600	2285600	SYDNOR	72	245	350			0110 0117	50	50	PZPB	IG	D	COM
										0132 0145						
123	C & P TELEPHONE CO	438200	2344500	ATLANTIC	72	164	330		268	0095 0105	8		KPTX	SDG	DE	COM
										0284 0294						
124	GLENDALE NAT CEMETERY	403800	2367200			140	232	133					TA	SDK		PUB
125	C D JONES	412600	2372400			150	286							UN		DOM
126	VA DEPT OF BLDGS&GRND	420600	2364900			140		132						UN		PUB
127	MOSMILLER GREENHOUSE	450800	2331200			175	303	179					KPTX	SDG		
128	JOHN TEPPER	401300	2346000			100	300	81						UN		DOM
129	CURLES NECK FARM	386700	2351900		00	30	725	33						UN		
130	ROBINWOOD SUB #3	429400	2334100		63	160	326	160			80		KLP	SDA		
131	U S TOBACCO CO						600	36	250		165					IND
132	FORT HARRISON													UN		PUB
133	M B ALEXANDER	392800	2358300	DOWDY	74	45	63	45								DOM
134	SYDNOR, RIDGECREST	462250	2269000		55		428	10	321	0087	31	47	PZPB	GR	D	
135	SYDNOR, RIDGECREST				56		457	11	102	0126	55	44	PZPB	GR	D	
136	SYDNOR, WISTAR FARMS/	471700	2286400		55	220	388	7	245	0058	33	51	PZPB	GR	D	
137	SYDNOR, WISTAR FARMS	472200	2285750		56	230	455	10	285	0103	10	88	PZPB	GR	D	
138	SYDNOR, HERMITAGE FMS	472500	2286700		56		435	4	291	0051	16		PZPB	GR		
139	SYDNOR, HERMITAGE FMS	472500	2286700		59		298	2	129		55		PZPB	GR		
140	SYDNOR, WEST WISTAR	468880	2280500		54		240	7	59	0090	82	57	PZPB	GR	D	
141	GROOMES BROS. REALTY			DOWDY	74		35	17					QS	SDG		DOM
142	SYDNOR, WOODLAWN FARM	471250	2282250		15	280	424	20	360	0196	6		PZPB	GR		
143	SYDNOR,MIMOSA PK #1	474850	2276250		53		226	12		0110		30	PZPB	GR	D	
144	SYDNOR, BONNIE BRAE	473550	2276800			280	175	6	155	0051	20		PZPB	GR		
145	SYDNOR, BONNIE BRAE	467600	2286800				101			0030	4		PZPB	GR		
146	SYDNOR, BONNIE BRAE				40		349	8	250	0038	18	35	PZPB	GR	D	
147	SYDNOR, NINE ACRES	465500	2291100		53		225	9		0052		15	PZPB	GR	D	

V I R G I N I A   S T A T E   W A T E R   C O N T R O L   B O A R D

B U R E A U   O F   W A T E R   C O N T R O L   M A N A G E M E N T   DATE 06/12/80

SUMMARY OF WATER WELLDATA FOR HENRICO COUNTY   PAGE 5

****

SWCB NO.	OWNER	VA. PLANE COORD NORTH	EAST	DRILLER	YR COMP	ELEV	TOT DEPTH	SWL	PUMP LEVEL	ZONES OR SCREENS	YIELD	BED-ROCK	FORM-ATION	LITH-OLOGY	LOGS	TYPE
148	SYDNOR, BILTMORE	481350	2301900		49	170		16	19	0104	60	44	PZPB	GR	D	
149	SYDNOR, COURTNEY	482500	2281100		56	285	370			0127	35	68	PZPB	GR	D	
150	SYDNOR, COURTNEY	485000	2282200		60	225	270	16		0088	55		PZPB	GR		
151	SYDNOR, CHAMBRLNE HTS	472600	2308050		39	190	277	82	100		60		PZPB	GR		
152	SYDNOR, CHAMBRLNE HTS	472700	2308350		43	185	300	100	104	0163	57		PZPB	GR		
153	SYDNOR, CHAMBRLNE HTS	470500	2307500		57	115	285	50	70	0111	220		PZPB	GR		
154	SYDNOR, CHAMBRLN HILL	475150	2310900		65	140	508	140	295	0230	66		PZPB	GR		
155	SYDNOR,MONTEZUMA #1	448000	2318000	SYDNOR	39	172	100				36					
156	SYDNOR, STRATFORD VIL	456900	2308450			195	432	37		0150		146	PZPB	GR		
157	SYDNOR, MECHVLE GDN	445500	2316300			165	240	123		0208 0229			PZPB	GR		
158	SYDNOR, NATIONAL HTS	431050	2323350		67	155	230	130		0205 0220	41			UN		
159	SYDNOR, COLONIAL CT	432500	2324100		40	159	166	108	140	0152 0162	20		KPTX	SDG	D	
160	SYDNOR, ROBIN GREY	433000	2325200			165	199	127		0169 0189			KPTX	SDG	D	
161	SYDNOR, EASTOVER GDN	434300	2327900		53	170	251	125		0219 0240			KPTX	SDG		
162	SYDNOR, ROBINWOOD	431700	2334550			165	196	127		0182 0196			KPTX	SDG	D	
163	SYDNOR, ROBINWOOD				56		448	142	175		12				D	
164	SYDNOR,WEDGEWOOD #2	430150	2328500		48	160	225	127		0190 0217			KPTX	SDG	D	
165	HENRICO CO. WOODCLIFF	485400	2303700			180										
166	HENRICO COUNTY	449500	2319700			165										
167	HENRICO COUNTY	457600	2320000			185										
168	HENRICO COUNTY	457600	2319500			185										
169	THOMPSON	434250	2354650	SYDNOR	73	155	595	170	249	0362 0380	700		KPTX	SDG	DEG	PWS
										0395 0406						
										0423 0444						
170	HENRICO CO. OBS. WELL	434275	2354675	SYDNOR	73	155	595	170		362 380		600	KPTX	SDG	DE	PWS
										395 406						
										423 444						
										572 590						
171	STANLEY ACARS			DOWDY	74		49	28					QS 3	SDG		DOM
172	B L BOWERY SR.	419500	2338300	DOWDY	74	155	38	24						QS		DOM
173	BRUCE H RAYMOND			DOWDY	74		40	15					QS 3	SDG		DOM
174	SUN OIL CO	479700	2263000		66	270										COM
175	GROOMES BROS REALTY	412500	2325800	DOWDY	74	140	56	38					QS	SDG		DOM
176	BEN ARMAND			DOWDY	74		44	25								DOM
177	WAYNE GRUBBS	422300	2338200	DOWDY	74	165	32	19					QS	SDG		DOM
178	SHERMAN STEVENS			DOWDY	74		45	25								DOM
179	RUSSELL WILLIS			DOWDY	74		43	20								DOM
180	FRANK CRAMBLITT			DOWDY	74		34	14								DOM
181	W H CORRETT			DOWDY	74		36	14					QS	SDG		DOM
182	HARRY SHUMATE			DOWDY	74		38	22					QS	SDG		DOM
183	R E ANDERSON			DOWDY	74		75	25					QS	SDG		DOM
184	CHESTERFIELD CONST CO	405100	2332400		74	135	31	18					QS	SDG		DOM
185	M A CAMPBELL			ASHLAND	75		30	16							D	DOM
186	FRED WALKER			ASHLAND	75		31	14					PZPB	GR	D	DOM
187	JONES & ROBBINS INC	430900	2334550	MITCHELL	53	165	244	135	200	0192 0222	118		KPTX	SDG	D	PWS

SWCB NO.	OWNER	VA. PLANE COORD NORTH	EAST	DRILLER	YR COMP	ELEV	TOT DEPTH	SWL	PUMP LEVEL	ZONES OR SCREENS	YIELD	BED-ROCK	FORM-ATION	LITH-OLOGY	LOGS	TYPE
188	LAUREL GOLF CLUB	478550	2286750			220							PZPB	GR		
189	W T SMITHDEAL	450000	2288850		70	240										PWS
190	B W FERGUSON	426200	2317400			125	210						PZPB	GR		PWS
191	UPJOHN NAT LEASING CO	465600	2284200	WATR WLLS	67	230	312	2	152		10		PZPB	GR	D	PWS
192	STATE POLICE 1ST DIV															PWS
193	ST CATHERINE'S SCHOOL	452650	2283650			278	245						PZPB	GR		PWS
194	EVERETT NUCHOLS	489900	2293900	MILLS	75	212	35	18					PZPB	GR	D	DOM
195	A G DAVIS	425000	2337800	DOWDY	75	165	52	18					QS	SDG		DOM
196	JAMES KIRBY			DOWDY	75		31	19					QS	SDG		DOM
197	R L MARSCKAK REALTY	425000	2337800	DOWDY	75	165	38	14					QS	SDG		DOM
198	GROOMES BROS REALTY			DOWDY	75		49	22								DOM
199	FLETCHEUS PAINT & BODY SHOP	478700	2300400	MILLS	75	205	41	22					PZPB	GR	D	DOM
200	SYDNOR HYDRODYNAMICS	431700	2324000	MITCHELL	75	155	264	156	176	0219 0254	45		KPTX	SDG	E	PWS
201	J SARGEANT REYNOLDS	476600	2296450	STUDENTS	75	165	220	24	216		37	216	PZPB	GR	D	PWS
202	A W DENTON	474550	2290700	MILLS	75	202	42	20					PZPB	GR	D	DOM
203	DUNNAVANT & WILLLIAMS			DOWDY	75		44	18					QS 3	SDG		DOM
204	DUNNAVANT & WILLIAMS			DOWDY	75		43	20					QS 3	SDG		DOM
205	E L FLEMING			DOWDY	75		51	35								DOM
206	MITCHELL HAMBIS			DOWDY	75		30	13					QS 3	SDG		DOM
207	JOHN B BUHRMAN			DOWDY	75		55	25					QS 4	SDG		DOM
208	DANIEL MATHEWS	475000	2254500	DOWDY	75	250	46	20					PZPB	GR		DOM
209	JACK FERGUSON JR			DOWDY	75		54	28								DOM
210	RALPH FERRELL			DOWDY	75		31	11					QS 3	SDG		DOM
211	ALLEYS AUTO REPAIR	462600	2286400	DOWDY	75	220	31	13					PZPB	GR		DOM
212	BARNIE MCGIRT CON	403500	2371100	DOWDY	75	145	43	20					QS	SDG		DOM
213	JULIUS A HARVATH			DOWDY	75		46	25								DOM
214	DUNNAVANT & WILLIAMS			DOWDY	75		38	20					QS 3	SDG		
215	ROBERTA MANUEL	433700	2363500	DOWDY	75	135	46	26					QS	SDG		DOM
216	H E GREEN			DOWDY	75		40	25								DOM
217																
218	MR COURTNEY	409200	2348300	DOWDY	76	140	53	40					QS	SDG		DOM
219	MITCHELL KAMBIS			DOWDY	75		39	19					QS	SDG		DOM
220	MITCHELL KAMBIS			DOWDY	75		38	18					QS	SDG		DOM
221	DUNAVENT & WILLIAMSON	417950	2355850	DOWDY	75	165	55	35					QS	SDG		DOM
222	HUNTER WHITLOCK	441000	2350500	DOWDY	76	150	42	18					QS	SDG		DOM
223	FLOYD FERRELL			DOWDY	75		29	9					QS 3	SDG		DOM
224	W J DERUSHER			DOWDY	75		44	24					PZPB	GR		DOM
225	MITCHELL KAMBIS			DOWDY	75		32	19								DOM
226	MITCHELL KAMBIS			DOWDY	76		35	14								DOM
227	FRANK DAVIS			DOWDY	74		30	15					QS	GR		DOM
228	L A LUBOLD	428200	2323400	DOWDY	74	115	41						TC	SIC		DOM
229	DUNAVANT & WILLIAMSON			DOWDY	75		50	25					QS	GR		DOM
230	ARNOLD GUNDERSON			DOWDY	76		39	22					QS 3	GR		DOM
231	K & D CONST CO			DOWDY	76		31	12					QS	GR		DOM
232	WM L GRUBBS			DOWDY	76		33	15					QS 3	GR		DOM

V I R G I N I A   S T A T E   W A T E R   C O N T R O L   B O A R D

B U R E A U   O F   W A T E R   C O N T R O L   M A N A G E M E N T   DATE 06/12/80

SUMMARY OF WATER WELLDATA FOR HENRICO COUNTY

****

SWCB NO.	OWNER	VA. PLANE COORD NORTH	VA. PLANE COORD EAST	DRILLER	YR COMP	ELEV	TOT DEPTH	SWL	PUMP LEVEL	ZONES OR SCREENS	YIELD	BED-ROCK	FORM-ATION	LITH-OLOGY	LOGS	TYPE
233	ROY GROOMES CONST CO	409700	2373300	DOWDY	75	140	43	22					QS	SDG		DOM
234	BARNIE MCGIRT			DOWDY	75		41	20					QS	GR		DOM
235	DAVE GOODING			DOWDY	75		50	25					QS	GR		DOM
236	GROOMES RROS CONST CO			DOWDY	75		55	37					QS	GR		DOM
237	F L BECHAM			DOWDY	76		40	20					QS	GR		DOM
238	DILLARD CONST CO			DOWDY	76		22	11								DOM
239	GREGORY CONST			DOWDY	75		40	15								IND
240	HENRY DAVIS			DOWDY			39									
241	ROBERT WALL			DOWDY	75		36	18					QS	GR		DOM
242	MITCHELL KAMBIS	409000	2352800	DOWDY	75	135	37	17					QS	SDG		DOM
243	LEE HY PAVING CORP	429400	2322600	DOWDY	75	140	49	19					TC	SID		DOM
244	DUNAVANT & WILLIAMSON			DOWDY	75		27	16					QS	GR		DOM
245	DUNAVANT & WILLIAMSON			DOWDY	75		44	20					QS	GR		DOM
246	LOCKE LANE APTS							6			80		PZPB	GR		
247	MORTON G THALHIMER IN			SYDNOR	77		266						PZPB	GR		
248	STEWART VEST	498800	2286000	SYDNOR	77	185	160	24	124		10		PZPB	GR		DOM
249	EWELL TINSLEY	492250	2253500	MATTHEWS	66	270	130						PZPB	GR		DOM
250	NURSERY #1			GENTRY			105						PZPB	GR	E	
251	REGAL INVESTMENT CO						300									
252	VARINA ELEMENTARY SCH	403500	2335000		77	138	250	99	119				KPTX	SDG		
253	MORTON G THALHIMER			SYDNOR	78		357	10	195		30					
256	SECOND CHURCH OF CHRIST	452000	2266500		78		400	80	378		80		PZPB	GR	G	
258	E. G. WADE JR.	450400	2329000	GAMMON		190				0200 0210 0230 0240	12		KPTX	SDG		
259	AWANAKENA	431250	2372200				45						TC	SID		
260	LAVERNE F. SNEAD	448000	2330500	BLACKWELL									QS 3	SDG		
261	A. C. TUCK	444800	2331900				25						QS 3	SDG		
262	IMOGNE ALLEN	427200	2359000		61											DOM
263	VET. OF FOREIGN WARS	434000	2350750	BLACKWELL			45						QS 3	SDG		DOM
264	JESSIE LEWIS JR.	428750	2351500	BLACKWELL			100									DOM
268	C. S. SALMON	476250	2286800				17						QS 2	SDG		DOM
269	MARGETT MONTGOMERY	447700	2344000				80									DOM
270	JERRY B. WINTON	442300	2354750													DOM
271	JOHN ROYSTEN SR.	442500	2348500				50									DOM
272	CHARLES C. HILL	427750	2349750	C. HILL			43						QS 3	SDG		
273	IRVIN R. GREEN	423250	2351500	A.E.BROWN			38						QS 3	SDG		
274	DALE ORION	400450	2346000													
275	J. A. BRAXTON	418800	2321400	DOWDY			4									
276	W. S. CARTER	449500	2326500													
277	JOHN K. STONNELL	465700	2257500				105						PZPB	GR		
278	ERNEST C. ROBERTSON	478200	2286750				22						QS 2	SDG		
279	MRS. COLLINS	464500	2302000													
280	MR. STOUT	490600	2278500		62		42						PZPB	GR		DOM
281	J. J. DUVALL	456800	2259200		51		15	12					QS 2	SDG		DOM
282	M. B. ALEXANDER	392800	2358300	DOWDY	75		65	53								DOM

V I R G I N I A   S T A T E   W A T E R   C O N T R O L   B O A R D

B U R E A U   O F   W A T E R   C O N T R O L   M A N A G E M E N T   DATE 06/12/80

SUMMARY OF WATER WELLDATA FOR HENRICO COUNTY   PAGE 8

****

SWCB NO.	OWNER	VA. PLANE COORD NORTH	EAST	DRILLER	YR COMP	ELEV	TOT DEPTH	SWL	PUMP LEVEL	ZONES OR SCREENS	YIELD	BED-ROCK	FORM-ATION	LITH-OLOGY	LOGS	TYPE
283	S. DANIELS	422350	2373600				35						QS 3	SDG		DOM
284	MR. EACHO	425000	2337800	DOWDY			38									
285	MR. BERNARNINA	444600	2354250			85	200						KPTX	SDG		
286	BISHOP MEM. METH. CH.	441850	2324200		53	150										DOM
287	GILBERT L. MILES	486400	2292700	SYDNOR	63	200	205						PZPB	GR		
288	W. H. SOUDER	457200	2258000	SYDNOR	62	2101										DOM
289	MR.&MRS. W.M. SNOWA	429250	2367000		72	155										DOM
290	JOHN TOBIN JR.	408400	2367200	DOWDY		150										DOM
291	MRS. CARL JONES	384900	2365500			40										
292	RUTH REYNOLDS	407900	2328200		68	150										
293	MARGARET MOORE	421900	2319450		56	160	125									DOM
294	MICHAEL GLEASON	479000	2265200		50	290							PZPB	GR		DOM
295	MR.&MRS. WM. W.TEMPLE	479200	2265200	NEWCOMB		290							PZPB	GR		DOM
296	HORACE LEWIS	479800	2271300		62	262							PZPB	GR		DOM
297	MARGRET MCDANIEL	488650	2273000	W.T.DAVIS	53	265	34						PZPB	GR		DOM
298	ELVIN COSBY	478500	2284100		60	245										DOM
299	IRENE P. COSLAY	481350	227600		42	240	15						PZPB	GR		DOM
300	ROBERT L. WHITE	489000	2257200			280							PZPB	GR		DOM
301	MICHEL S. YOUSSEF	416000	2339000	GAMMON	79	135	244	120		0224 0244	35		KPTX	SDG	D	PWS
302	M. FRANGER	476000	2301500			195							PZPB			
303	D. POORE	481200	2304500			195										
304	DOUG MITCHELL	435300	2363900			115	33	15					TC			DOM
305	SHELL OIL CO.	442200	2322300	MITCHELL	67	120	213			0138 0180	20		KPTX	SDG		
306	TEXACO CO.	442400	2321900	MITCHELL	67	120	189			0179 0189	12		KLP	SDA		
307	HERMITAGE COUNTRY CLUB	468400	2300400	SYDNOR	65	135	300			0070 0300	70		PZPB	GR		
308	LONNIE PARRISH	439500	2321000	SYDNOR	77	145	148			0110 0120	5					
309	BROOKFIELD HOME. INC.	490700	2301900	SYDNOR	67	130	204	71		0084 0144 0150	50		PZPB	GR		
310	U. S. DEPARTMENT OF INTERIOR	434400	2347500	SYDNOR		162	190			0005	10		TKM	SDD		
311	MR. HENRY STERN	481100	2264500	SYDNOR	66	260	435				1		PZPB	GR		
312	WESTWOOD RACQUET CLUB	459400	2286500			235							PZPB			

VIRGINIA STATE WATER CONTROL BOARD

BUREAU OF WATER CONTROL MANAGEMENT

SUMMARY OF WATER WELLDATA FOR HENRICO COUNTY

****

TOTAL NUMBER OF WELLS = 306

PARAMETER	OBSERVATIONS	MAXIMUM	MINIMUM	MEAN
ELEVATION	183	2101	12	179
TOTAL DEPTH	257	725	4	212
STATIC WATER LEVEL	199	210	0	68
PUMPING WATER LEVEL	99	400	0	193
YIELD	133	700	1	81
DEPTH TO BEDROCK	38	640	13	138

APPENDIX V

Summary of Ground Water Quality Analyses for Henrico County

VIRGINIA STATE WATER CONTROL BOARD

BUREAU OF SURVEILLANCE AND FIELD STUDIES — DATE 05/28/80

SUMMARY OF GROUNDWATER QUALITY ANALYSES FOR HENRICO COUNTY — PAGE 1

SWCB NO	OWNER AND/OR PLACE	DATE SAMP	PH	SPEC COND	T-DIS SOLID	HARDNESS TOTAL	HARDNESS CA,MG	FE	MN	CA	MG	NA	K	ALK	SO4	CL	NO3
1	INSULROCK CO	8 69	6.6	220	124	90	60			19.0	2.7	14.0	2.7	36	32.0	20.0	12.0
2	HECHLER VILLAGE	7 73	8.4	307	274	69	69	0.10	0.02	16.3	6.9	42.9	11.0	161	8.6	5.5	0.2
2	HECHLER VILLAGE	8 69	7.8	350	215	54	54			15.0	4.0	55.0	14.0		8.2	6.8	2.7
2	HECHLER VILLAGE	5 66	8.2		210		81	0.02	0.00	21.0	6.9	47.3		207	2.9	6.0	0.9
4	VARINA HIGH SCHOOL	6 78	6.9	158	110	54	64		0.01	21.0	3.0	5.0	2.0	33	25.0	11.0	
4	VARINA HIGH SCHOOL	12 72	8.3	7400	3870	460	250	0.23		82.0	12.0	1400.0	4.7	54	140.0	2200.0	0.0
5	OSBORNE PIKE	8 69	7.8	322	208		36			9.8	2.8	56.0	8.6		12.0	8.2	2.2
6	GLENWOOD GOLF COURSE	6 78	7.4	279		76	89		0.03	21.0	9.0	21.0	18.0	134	9.0		0.4
6	GLENWOOD GOLF COURSE	8 69	6.8	288	178	86	86	0.00		26.0	5.3	21.0	14.0	158	11.0	2.2	0.4
7	CIVIL DEFENCE CENTER	6 78	7.5	282		80	92	0.00	0.00	24.0	8.0	21.0	18.0	131	13.0	0.0	
8	EXXON	6 78	7.5	308		32	25	0.00	0.00	7.0	2.0	63.0	9.0	145	13.0	0.0	0.1
9	VARINA HIGH SCHOOL	8 69	8.0	321	199	124	124			43.0	4.2	17.0	6.2	190	8.2	5.0	1.3
10	COMMONWEALTH GRAVEL CO	6 78	7.8			40								162	8.0	1.0	0.7
10	COMMONWEALTH GRAVEL CO	8 69	7.8	345	219	39	39			12.0	2.1	56.0	13.0	177	13.0	9.0	2.7
11	VARINA ELEM SCHOOL	6 78	6.6	103		14	26	3.00	0.08	9.0	1.0	15.0	3.0	37	7.0	7.0	
11	VARINA ELEM SCHOOL	11 72	6.7	104	96	12	12	0.00		3.1	1.2	13.0	3.4	36	6.8	4.6	0.0
11	VARINA ELEM SCHOOL	8 69	6.7	91	90	12	12			3.8	0.6	16.0	2.7	44	6.6	5.2	0.4
12	FORT HARRISON	6 74		472			41	0.00	0.00	10.0	4.0	69.0	13.0				
12	FORT HARRISON	6 74	6.2	50	179	27	5	3.30	0.03	1.2	0.7	3.2	5.2	8	13.8	3.0	0.0
12	FORT HARRISON	12 72	5.8	52	67	7	7	0.04		1.4	0.9	3.4	5.9	8	10.0	2.4	0.0
12	FORT HARRISON	6 72	7.5			18	18	0.20	0.02	7.2	0.2	35.2	3.8	86		2.5	
12	FORT HARRISON	2 68	8.2			34	32	0.18	0.00	12.8	0.1	25.2	1.3	92	10.5	3.5	0.2
13	BRADLEY ACRES	6 78	7.6	301		4	2	0.00	0.00	1.0	0.0	66.0	4.0	130	8.0	1.0	0.0
13	BRADLEY ACRES #1	3 72	8.6			16	16	0.11	0.03	6.4	0.1	63.5	9.5	152	5.8	1.5	0.1
13	BRADLEY ACRES #1	6 71	8.3			11	5	0.07	0.00	1.6	0.3	69.0	7.8	133	11.6	9.0	
13	BRADLEY ACRES #1	12 67	8.3				6	0.08	0.00	2.0	0.2	63.9			8.2	13.0	2.2
13	BRADLEY ACRES #1	11 67	8.2			4	3	0.34	0.02	0.6	0.6	67.0	30.0	123	24.0	9.5	
14	HECHLER VILLAGE	8 69	8.0	336	202	54	54			16.0	3.4	50.0	11.0	187	10.0	5.2	0.4
14	HECHLER VILLAGE	9 58	7.9					0.05	0.00							5.4	1.3
15	YORK MANOR	8 69	7.8	290	194	72	72			23.0	3.4	33.0	6.6	168	7.6	3.5	4.0
15	YORK MANOR	5 64	8.2		204	28	22	0.06	0.00	6.8	1.4	48.2			3.5	2.5	0.0
16	HECHLER VILLAGE	6 78	7.4	293		53	56	0.00	0.02	16.0	4.0	27.0	7.0	97	14.0	6.0	0.8

NOTE--ALL ZEROS (00.00) - ANALYSED, NOT DETECTED; ALL NINES (99.99) - COULD NOT BE STORED, REFER TO ANALYSIS

NOTE--ALL ZEROS (00.00) - ANALYSED, NOT DETECTED! ALL NINES (99.99) - COULD NOT BE STORED, REFER TO ANALYSIS

SWCB NO	OWNER AND/OR PLACE	DATE SAMP	PH	SPEC COND	T-DIS SOLID	HARDNESS TOTAL	HARDNESS CA,MG	FE	MN	CA	MG	NA	K	ALK	SO4	CL	NO3
16	HECHLER VILLAGE	7 73	8.4	188	252		49	0.00	0.01	11.0	5.3	46.0	12.0	156	6.6	4.5	0.0
16	HECHLER VILLAGE	8 69	7.8	300	191		60			21.0	1.7	37.0	8.6		8.8	3.2	1.3
16	HECHLER VILLAGE	2 59	8.0				58	0.18	0.00	15.2	4.9	47.7			4.4	4.0	0.4
16	HECHLER VILLAGE	11 58	8.6					0.96	0.09							6.7	0.4
16	HECHLER VILLAGE	3 57	7.6					0.00									
17	LEWIS GARDENS	6 78	7.6	358		54	62	0.70	0.05	20.0	3.0	53.0	5.0	122	9.0	8.0	0.2
17	LEWIS GARDENS #1A	1 74	8.2	241				0.16	0.04					116			
17	LEWIS GARDENS #1A	9 72	7.8			71	70	1.94	0.35	24.0	2.7	14.0	4.6	98	9.5	3.5	0.0
17	LEWIS GARDENS #3	6 51	7.1				68	1.20	0.35	22.9	2.7				2.7	11.5	
18	LEWIS GARDENS #3A	9 72	8.0		259	48	47	1.62	0.16	15.2	2.4	57.0	4.5	113	18.8	38.5	0.0
18	LEWIS GARDENS #2	6 51	7.1				64	3.60	0.35	21.3	2.6				1.8	9.7	
19	HIGHLAND SPRINGS	8 69	7.6	294	196		77			26.0	2.9	30.0	8.6		6.6	3.3	0.4
19	HIGHLAND SPRINGS	5 61					103	0.12	0.00	29.0	7.4	21.0			2.0	3.5	
20	GILLIES CREEK WELL	4 72	8.7		258	41	41	0.16	0.00	11.2	3.2			154	11.5	2.5	0.2
21	COMMONWEALTH NAT GAS	6 78	6.3	235		80	77	1.50	0.01	18.0	8.0	7.0	8.0	31	55.0	1.0	3.1
22	EASTOVER GARDENS	8 69	7.8	352	220		36			10.0	2.3	61.0	12.0		17.0	6.8	1.3
23	OBS WELL #23	3 73	7.2	250	149		22	0.08		7.1	1.0	50.0	1.8		4.0	4.2	2.7
23	OBS WELL #23	3 72	6.7	64	580		11	0.02		3.0	0.8	7.8	1.7		0.4	3.4	0.4
23	OBS WELL #23	3 72	6.6	64	54		8	0.02		2.4	0.6	9.0	1.6		0.4	4.4	0.4
23	OBS WELL #23	1 70	8.3	390	228		4	0.18		1.3	0.2	90.0	2.1		4.6	4.4	0.0
24	BESSIRE & CO	5 78	8.4	1541		6	11	0.10	0.60	3.0	1.0	35.0	3.0	196	189.0	230.0	
24	BESSIRE & CO	12 72	9.0	1750	1026		9	0.02		2.2	0.9	380.0	5.0		230.0	260.0	0.0
24	BESSIRE & CO	8 69	8.8	1680	906		12			3.6	0.7	333.0	3.5		191.0	244.0	2.7
24	BESSIRE & CO	5 67													175.0	215.0	
24	BESSIRE & CO	4 67	9.4				11	0.06	0.03	3.2	0.8				200.0	237.5	4.4
25	HIGHLAND SPRINGS #1	5 78	7.9	260		48	42			12.0	3.0	4.0	2.0	133	13.0	5.0	
25	HIGHLAND SPRINGS #1	11 36					43	0.40		14.1	1.8				9.9	1.0	
27	R G FORE	7 74	6.2	58			31	0.10		12.0	0.5	4.0	0.7	29	0.0	4.0	0.4
27	HIGHLAND SPRINGS	5 54	7.5				94	0.26	0.00	28.9	5.3				5.1	10.3	0.4
28	HIGHLAND SPRINGS #4	8 58	8.0				103	0.12	0.00	32.2	5.6	25.7			2.7	2.1	2.2
29	LAWNDALE FARMS #2	11 71	8.5		211	42	41	0.05	0.00	12.8	2.3	53.0	11.0	160	11.0	3.5	
30	LAWNDALE FARMS #1	11 71	9.3		216	40		0.02	0.03	12.8		53.0	11.5	156	10.0	6.0	
30	LAWNDALE FARMS #1	3 57	6.9			30		0.30						77		3.0	

NOTE--ALL ZEROS (00.00) - ANALYSED, NOT DETECTED! ALL NINES (99.99) - COULD NOT BE STORED, REFER TO ANALYSIS

****

SWCB NO	OWNER AND/OR PLACE	DATE SAMP	PH	SPEC COND	T-DIS SOLID	HARDNESS TOTAL	CA,MG	FE	MN	CA	MG	NA	K	ALK	SO4	CL	NO3
33	SANDSTON #1	12 68	7.8				96	0.18	0.00	26.0	7.6	25.8			3.3	5.0	0.9
34	SANDSTON #2	1 69	7.8				99	0.70		27.0	7.6	27.3			3.3	4.0	1.3
34	SANDSTON #2	12 68	7.7				100	5.10	0.00	27.0	7.9	22.1			3.7	5.0	1.3
35	SANDSTON #3	12 68	7.5				98	0.14	0.00	26.5	7.8	22.4			3.9	5.0	0.9
36	SANDSTON #4	12 68	7.6				106	0.05	0.00	29.0	8.2	25.3			3.7	5.0	0.9
37	SANDSTON #5	12 68	7.8				98	0.13	0.00	27.0	7.4	28.9			3.5	5.0	0.9
38	L M KNIGHT	7 74	5.6	73			20	0.10		6.0	1.4	10.0	2.1	6	8.2	11.0	16.4
40	VIRGINIA HEIGHTS	11 71	7.5		193	21	20	0.04	0.01	8.0	0.2	54.0	7.0	113	12.8	21.0	
42	WINDSOR PLACE	11 71	8.5		230	64	63	0.00	0.02	16.8	5.2	48.5	12.5	173	8.8	4.5	
43	MAYFIELD FARMS	4 72	8.0		279	123	120	0.06	0.00	28.7	11.9	36.0	17.7	167			1.3
45	CHAMBERLAYNE FARMS #1	1 62	7.5					0.01	0.11							27.3	
47	CHAMBERLAYNE FARMS #3	11 58	7.8					0.30	0.07							19.4	0.4
48	CHAMBERLAYNE FARMS #4	1 62	7.9			157		0.40	0.11							18.0	2.7
48	CHAMBERLAYNE FARMS #4	11 58	7.8			117		0.25	0.11							3.8	0.4
49	CHAMBERLAYNE FARMS #5	1 62	7.9			*		0.16	0.11							18.5	0.4
54	SAN RAFAEL COURT	7 73	8.1	303	190	102	105	0.06	0.08	25.0	10.4	19.5	9.0	138	10.0	2.0	0.1
57	WOODLAWN FARMS	5 78	7.0	120	121	34	34	0.10		9.0	3.0	10.0	2.0	58	8.0	4.0	
59	WESTWOOD MANOR	9 72	6.9		110	38	38	0.00	0.00	8.0	4.4	8.0	2.4	47	2.6	3.5	1.3
59	WESTWOOD MANOR #1	4 53	6.7			51		0.10						70		2.0	
60	GILBERT GARDENS	6 78	7.9	338	217	32	32	0.00	0.00	8.0	3.0	59.0	11.0	153	13.0	1.0	
61	GILBERT GARDENS	6 78	7.9	346	219	32	34	0.00	0.01	9.0	3.0	59.0	11.0	150	13.0	1.0	
61	GILBERT GARDENS	8 73	8.1		226	34	53	0.04	0.00	13.8	4.6	34.5	14.5	149	149.0	5.5	
62	COUNTY OF HENRICO	5 78	8.1	307		16	18		0.01	4.0	2.0	63.0	9.0	145	16.0	3.0	
62	COUNTY OF HENRICO	8 69	8.5		269	26	25	0.05		9.5	0.5	88.9		126	11.5	49.0	
63	KELLY'S RESTAURANT	6 70	8.0	348	224		42	0.04		13.0	2.3	61.0	15.0		7.4	7.8	0.4
64	BLUE CROSS/BLUE SHIELD	5 80	6.8	1422	150	54	54	0.10	0.01	17.0	3.0	4.0	1.0	24	31.0	8.0	1.1

NOTE--ALL ZEROS (00.00) - ANALYSED, NOT DETECTED; ALL NINES (99.99) - COULD NOT BE STORED, REFER TO ANALYSIS

VIRGINIA STATE WATER CONTROL BOARD

BUREAU OF SURVEILLANCE AND FIELD STUDIES

DATE 05/28/80

SUMMARY OF GROUNDWATER QUALITY ANALYSES FOR HENRICO COUNTY

****

SWCB NO	OWNER AND/OR PLACE	DATE SAMP	PH	SPEC COND	T-DIS SOLID	HARDNESS TOTAL	CA.MG	FE	MN	CA	MG	NA	K	ALK	SO4	CL	NO3
69	LEWIS GARDENS #2	8 73	7.3	190	180	7	69	3.85	0.25	22.5	3.3	22.5	4.9	107	6.3	6.5	0.1
71	AIRCO WELDING	8 79	7.8	3500	2034	166	196	0.00	0.02	49.0	18.0	690.0	22.0	192	310.0	855.0	
77	SWCB / DES	8 78	7.2	221	165	78	76	0.10	0.09	24.0	4.0	19.0	3.0	94	17.0	7.0	0.0
82	BESSIE MANEY	7 74	6.0	125			36	0.00		12.0	1.5	17.5	5.3	34	10.4	13.0	31.0
83	PINE HEIGHTS	11 72	7.7	350	204	140	140	0.00	2.60	34.0	14.0	2.6	18.0	209	3.9	1.9	1.8
83	PINE HEIGHTS	3 72	8.1		222	143	142	0.01	0.03	36.0	12.9	8.5	16.0	171	4.5	1.0	0.4
86	WESTBRIAR ROAD	8 78	6.9	188	130	66	75	0.00	0.01	22.0	5.0	8.0	2.0	26	52.0	19.0	
87	MCDONALDS RESTAURANT	6 79	7.8	329		42	46	0.00	0.01	12.0	4.0	52.0	12.0	156	7.0	0.0	
89	COLUMBIAN COMM CTR	6 78	6.4	126	126	32	32	0.00	0.03	8.0	3.0	10.0	2.0	37	8.0	8.0	
89	COLUMBIAN COMM CTR	3 71	7.1		114	41	42	1.75	0.11	12.0	3.0			46	4.4	7.0	
91	C & P TELEPHONE CO	8 78	7.9	371	196	96	90	0.20	0.01	23.0	8.0	30.0	13.0	150	10.0	2.0	0.6
91	C & P TELEPHONE CO	3 77	8.1		254	30	35	0.25	0.01	9.6	2.9	72.0	13.2	158	11.0	6.0	
92	HECHLER VILLAGE	8 77	8.2		228	28	28	0.04	0.04	9.6	1.0	58.0	11.0	143	10.8	35.0	
94	DEEP RUN MANOR	11 77	7.4		178	81		0.42	0.16	24.0		16.5	2.1	93	13.0	6.5	
99	MASONIC HOME OF VA	4 77	8.5		200	88	88	0.10	0.03	22.5	7.9	35.5	12.5	302	7.8	3.5	0.0
101	COUNTY OF HENRICO	4 78	6.1	104		22	21	0.00	0.01	7.0	1.0	10.0	1.0	18		15.0	7.1
102	BYRD AIRPORT	7 40	7.4					1.40						195		7.0	
103	CANTERBURY SUB #3	1 61	8.0		180	107	107	0.38	0.25	33.6	5.6	37.5		122	5.6	2.9	0.0
104	GINTER GARDENS	3 62	6.7			63		0.81	0.33					71	5.3	5.3	1.3
105	[illegible]	[illegible]	7.4		193	112	112	0.25	0.05	33.3	7.0			164	22.5	9.5	
106	[illegible]	[illegible]	7.[illegible]		191	94	91	0.15	0.04	26.3	6.2			158	13.1	9.1	3.1
107	[illegible]	[illegible]	[illegible]		205	50	49	0.39	0.00	13.5	3.8	61.2		164	1.6	1.7	3.1
108	[illegible]	[illegible] 74		91													26.5
108	[illegible]	[illegible]	5.[illegible]	[illegible]	109	25	22	0.10	0.00	6.5	1.5	11.5		34	0.0	7.5	17.1
108	[illegible]	[illegible]	6.[illegible]		64		23	0.06	0.00	7.4	1.1	1.7		19	0.2	5.9	64.2
109	[illegible]	[illegible]	7.[illegible]			44		8.50	1.00								

NOTE-- [illegible] REPORTED: ALL NINES (99.99) - COULD NOT BE STORED, REFER TO ANALYSIS

SUMMARY OF GROUNDWATER QUALITY ANALYSES FOR HENRICO COUNTY

SWCB NO	OWNER AND/OR PLACE	DATE SAMP	PH	SPEC COND	T-DIS SOLID	HARDNESS TOTAL	CA.MG	FE	MN	CA	MG	NA	K	ALK	SO4	CL	NO3
109	LAKESIDE COUNTRY CLUB	3 35	6.7			74								61	14.0	4.0	
110	LAKESIDE COUNTRY CLUB	7 78	7.2	362		50	70	0.80	0.02	20.0	5.0	41.0	2.0	83	78.0	4.0	0.3
110	LAKESIDE COUNTRY CLUB	7 73	8.2	288	230	90	92	0.40	0.00	25.0	7.4	27.5	3.1	82	65.2	4.0	0.2
110	LAKESIDE CO CLUB #2	10 63	7.7			138		7.82	0.75					41			
111	LEWIS GARDENS #1	6 51	7.1	169	169	62	62	2.50	0.35	18.1	4.0			80	2.7	10.3	
111	LEWIS GARDENS #1	2 50	6.8		169	63	63	2.00	0.30	22.3	1.9			58	4.4	10.3	1.3
112	C M SPROUSE	7 74	7.3	262			132	0.20		35.0	10.9	17.0	20.4	165	5.7	4.0	0.0
113	A W ROBINSON	7 74	6.3	98			54	1.20		18.0	2.3	9.3	0.4	53	2.4	6.0	1.8
114	LITTLE OIL CO	7 53	6.3			100		0.90						130		9.1	
114	LITTLE OIL CO	7 53	6.4					1.50								8.5	
115	DABBS HOUSE (CD)	9 67	7.7		199	110	102	0.08	0.04	28.9	7.2	17.0	5.3	147	5.4	38.0	0.4
115	DABBS HOUSE (CD)	10 65	8.4	174	174	96	81	0.87	0.03	25.0	4.6	22.2		137	3.5	2.3	1.8
115	DABBS HOUSE (CD)	4 65	8.3			91	90	1.84	0.03	25.4	8.7	10.9		112	9.7	1.8	1.8
115	DABBS HOUSE (CD)	7 64	8.2		187	98	98	0.10		24.0	9.2	20.6		140	4.1	4.0	
116	I-95 REST AREA #1	6 66	9.0				21	2.32	0.00	4.0	2.6			232	3.3	4.0	0.0
117	I-95 REST AREA #2	6 70	7.7	592												15.0	
117	I-95 REST AREA #2	6 66	8.4				99		0.85	22.4	10.4						0.0
118	SANBOURNE PARK	6 78	7.5	262		26	28	0.00	0.02	8.0	2.0	46.0	7.0	106		4.0	6.3
120	FORT HARRISON	8 69	6.9	175	120	56	56			20.0	1.2	9.0	7.0	89	7.6	3.5	0.4
124	GLENDALE NAT CEMETRY	11 72	7.7	390	235	110	110	0.08		28.0	10.0	24.0	24.0	219	6.9	3.0	0.4
127	CREIGHTON ROAD	12 72	7.7	330	207	22	22	0.05		5.8	2.0	60.0	16.0	177	14.0	3.0	2.2
128	UNION GROVE CHAPEL	11 72	6.9	275	187	1	1	0.22		0.2	0.1	64.0	0.4	135	11.0	7.8	9.3
129	CURLES NECK	11 72	7.2	370	242	2	2	0.06		0.4	0.4	78.0	8.1	141	11.0	34.0	0.0
132	COUNTY OF HENRICO #1	10 73	8.0		234	76	76	1.61	0.09	15.1	9.4	51.9		192	15.2	13.0	
132	FORT HARRISON	2 68	8.2			34	32	0.18	0.00	12.8	0.1	25.2	1.3	47	10.5	3.5	0.9
133	M B ALEXANDER	8 78	7.8	433	268	144	169	1.00	0.24	48.0	12.0	30.0	10.0	161	12.0	35.0	4.0
134	RIDGECREST #2	1 74	7.5	88				0.03	0.01					62			
134	RIDGECREST #2	5 73	6.8		100	29	29	0.00	0.01	9.2	1.5	10.3	1.9	92	0.2	4.5	0.6
134	RIDGECREST #2	11 55	6.4			85		0.20						94		8.0	

NOTE--ALL ZEROS (00.00) - ANALYSED, NOT DETECTED; ALL NINES (99.99) - COULD NOT BE STORED, REFER TO ANALYSIS

VIRGINIA STATE WATER CONTROL BOARD

BUREAU OF SURVEILLANCE AND FIELD STUDIES

DATE 05/28/80

SUMMARY OF GROUNDWATER QUALITY ANALYSES FOR HENRICO COUNTY

SWCB NO	OWNER AND/OR PLACE	DATE SAMP	PH	SPEC COND	T-DIS SOLID	HARDNESS TOTAL	CA.MG	FE	MN	CA	MG	NA	K	ALK	SO4	CL	NO3
135	RIDGECREST	12 51	7.3			77		0.00						100		4.0	
140	WEST WISTAR	1 74	8.0	128	122	19	18	0.04	0.01	4.9	1.5	25.5	2.4	80	0.0	1.0	0.8
140	WEST WISTAR	10 73	7.0	51	79	14	12	0.00	0.00	3.6	0.9	14.5	2.1	26	0.0	1.5	0.5
140	WEST WISTAR	11 66	7.5		71	22	19	0.06	0.03	4.0	2.2			28	0.3	2.5	
140	WEST WISTAR	2 54	6.2			22		0.40						24		22.0	
143	MIMOSA PARK	9 72	7.0		90	25	24	0.00	0.00	7.2	1.7	7.5	1.3	37	0.6	2.0	0.1
143	MIMOSA PARK	3 53	6.5					0.10						42		6.0	
148	BILTMORE	3 73	7.0		159	75	75	3.20	0.40	21.3	5.4	16.5	3.1	90	15.9	2.6	0.0
148	BILTMORE	10 71	8.0			76	76	4.00	0.07	22.4	4.9	36.0	3.0	127	16.1	2.5	
150	COURTNEY	6 78	6.0	69		19	22	0.10	0.01	9.0	0.0	2.0	0.0	29		2.0	0.0
150	COURTNEY	9 72	6.9		86	19	19	0.00	0.00	4.0	2.2	7.5	1.8	34	0.6	1.5	0.2
150	COURTNEY	2 71	6.7		96	20	20	0.09	0.02	6.4	1.1	15.8		48	1.2	4.0	
155	MONTEZUMA FARMS	3 69	6.6					0.02	0.02	0.8				4	0.0	5.0	
155	MONTEZUMA FARMS	8 38	5.9			10		0.60						12		9.0	
156	STRATFORD VILLAGE	9 74	7.8	530	378	128	124	0.48	0.15	26.8	13.9	72.0	6.5	161	106.8	19.0	0.2
156	STRATFORD VILLAGE	10 71	8.1			124	124	0.20	0.11	29.6	12.2	78.0	6.6	176	84.0	19.0	
157	MECHANICSVILLE GARDEN	12 72	8.2		265	110	109	0.00	0.02	30.4	8.2			139	52.8	3.6	
158	NATIONAL HEIGHTS	2 72	8.0		220	57	56	0.06	0.13	16.0	4.1	51.0	9.5	159	9.6	3.0	0.0
164	WEDGEWOOD FARMS	8 73	8.1	264	215	46	50	0.20	0.03	13.3	4.3	2.7	9.5	139	11.4	3.0	0.0
164	WEDGEWOOD FARMS	8 55	7.7			28		0.00						160		6.0	
165	WOODCLIFF	11 71	8.4		176	124	124	0.03	0.05	33.7	9.8	11.5	5.5	143	9.6	8.0	
169	COUNTY OF HENRICO	7 78	7.7	346	215	142	163	0.00	0.02	39.0	16.0	10.0	17.0	174	6.0	1.0	
169	COUNTY OF HENRICO	10 73	8.0		234	76	76	1.61	0.09	15.1	9.4	51.9		158	15.2	13.0	
174	STOUFFER SUNOCO	12 74	6.9	129			51	0.20		15.0	3.5	11.0	1.5	57	1.0	6.0	11.1
187	ROBINWOOD	6 74	7.6			22		0.14	0.04					149	24.2	125.5	
187	ROBINWOOD	8 73	7.7		450	22	25	0.12	0.01	5.8	2.6	160.0	11.5	155	22.4	127.0	0.1
188	LAUREL GOLF CLUB	5 73	7.5		368	57	61	0.80	0.10	16.3	5.0	90.0	6.2	186	100.0	56.5	6.0
189	LOCH LANE APARTMENTS	9 73	7.7	133	100	47	50	0.06	0.00	15.5	2.9	13.8	3.3	63	6.8	3.0	1.8
190	MARION HILLS	5 73	7.8		204	77	76	0.10	0.07	17.5	8.1	32.8	1.3	269	14.0	6.0	0.5

NOTE--ALL ZEROS (00.00) - ANALYSED, NOT DETECTED: ALL NINES (99.99) - COULD NOT BE STORED, REFER TO ANALYSIS

VIRGINIA STATE WATER CONTROL BOARD

BUREAU OF SURVEILLANCE AND FIELD STUDIES

DATE 05/28/80

SUMMARY OF GROUNDWATER QUALITY ANALYSES FOR HENRICO COUNTY

PAGE 7

SWCB NO	OWNER AND/OR PLACE	DATE SAMP	PH	SPEC COND	T-DIS SOLID	HARDNESS TOTAL	HARDNESS CA,MG	FE	MN	CA	MG	NA	K	ALK	SO4	CL	NO3
192	VA STATE POLICE	7 73	8.3	198	156	91	94	0.49	0.35	21.8	9.8	10.0	3.6	105	7.0	2.0	0.0
197	EACHO	8 78	6.8	442	285	94	115	0.00	0.04	38.0	5.0	17.0	11.0	34	20.0	21.0	68.7
200	EANES LANE	7 78	7.8	309	205	34	32	0.00	0.00	8.0	3.0	61.0	10.0	140	20.0	5.0	
211	ALLEY AUTO REPAIR	7 78	7.5	580		214	259	0.20	0.02	99.0	3.0	23.0	20.0	227	15.0	17.0	
221	DUNAVENT & WILLIAMS	7 78	6.0	56	45	16	12	0.00	0.01	5.0	0.0	4.0	2.0	14	3.0	6.0	
233	DARRYTOWN ROAD	7 78	6.1	193	144	30	49	0.00	0.02	10.0	6.0	16.0	3.0	43	2.0	24.0	
243	LEE HY PAVING CO	7 78	6.7	346	212	108	126	0.20	0.32	44.0	4.0	30.0	5.0	98	13.0	37.0	
249	EWELL & RENA TINSLEY	7 78	6.4	108	107	23	16	0.00	0.01	5.0	1.0	12.0	0.0	38	2.0	2.0	
254	VDH&T ELKO RES SHOP	8 78	7.7	291	184	26	32	0.40	0.00	8.0	3.0	46.0	13.0	138	12.0	2.0	0.0
255	E L PORTER	8 78	6.7	96	76	32	39	0.00	0.00	14.0	1.0	4.0	2.0	30	3.0	5.0	9.0
259	AWANAKENA	8 78	6.4	87	61	16	18	0.90	0.07	4.0	2.0	7.0	2.0	17		11.0	0.9
260	LAVERNE F SNEAD	10 78	6.7	193	135	60	70	0.00	0.03	20.0	5.0	10.0	2.0	23	44.0	9.0	14.6
261	A C TUCK	10 78	6.5	227	134	22	28	0.20	0.02	8.0	2.0	28.0	3.0	31	14.0	41.0	6.5
262	IMOGNE ALLEN	10 78	6.2	26	25	4	4	0.00	0.04	2.0	0.0	3.0	1.0	8	2.0	3.0	0.2
263	V F W	10 78	6.4	99	65	14	17	0.00	0.01	7.0	0.0	11.0	1.0	18	3.0	15.0	3.5
264	JESSIE LEWIS	10 78	6.6	153	81	18	23	0.20	0.16	6.0	2.0	15.0	2.0	17	3.0	15.0	17.3
265	J G STANLEY	9 78	6.5	111	102	25	30	0.00	0.03	9.0	2.0	9.0	4.0	31	2.0	9.0	19.9
266	J A COLEMAN	9 78	6.2	96	81	21	22	0.00	0.03	4.0	3.0	5.0	5.0	14	3.0	9.0	22.2
267	JIM C FLEMMING	9 78	6.6	81	84	17	19	0.30	0.02	6.0	1.0	8.0	3.0	47	2.0	0.0	0.0
268	C S SALMON	9 78	6.4	92	62	18	21	0.20	0.01	7.0	1.0	9.0	2.0	20	6.0	15.0	0.4
269	MARGETT MONTGOMERY	9 78	6.2	58	41	10								11	4.0	2.0	8.4
270	JERRY P HINTON	9 78	6.2	60	46	13								11	2.0	1.0	16.4
271	JOHN ROYSTER	9 78	6.1	57	35	8								11	2.0	12.0	3.5

NOTE--ALL ZEROS (00.00) - ANALYSED, NOT DETECTED; ALL NINES (99.99) - COULD NOT BE STORED, REFER TO ANALYSIS

SWCB NO	OWNER AND/OR PLACE	DATE SAMP	PH	SPEC COND	T-DIS SOLID	HARDNESS TOTAL	CA,MG	FE	MN	CA	MG	NA	K	ALK	SO4	CL	NO3
272	C C HILL	9 78	5.9	32	26	3								7	4.0	63.0	3.5
273	IRVIN R GREEN	9 78	5.9	70	26	9								8	2.0	1.0	5.8
274	DALE ORION	8 78	6.7	2443	168	44	48	1.60	0.09	16.0	2.0	29.0	1.0	45	7.0	43.0	6.1
275	J A BRAXTON	8 78	7.0	222	126	54	64	0.10	0.04	21.0	3.0	15.0	5.0	59	7.0	22.0	9.3
276	W S CARTER	8 78	6.1	128	96	34	20	0.30	0.01	5.0	2.0	11.0	2.0	24	6.0	15.0	18.2
277	JOHN K STONNELL	8 78	7.6	421	250	166	171	0.40	0.71	54.0	9.0	25.0	2.0	184	11.0	23.0	0.0
278	MR ROBERTSON	8 78	6.7	74	81	18	22	0.10	0.00	9.0	0.0	7.0	2.0	40	5.0	4.0	0.0
279	MRS COLLINS	8 78	6.1	54	37	16	9	1.10	0.03	4.0	0.0	3.0	1.0	13	7.0	5.0	0.0
280	STOUT	8 78	7.0	125	98	48	59	0.00	0.00	24.0	0.0	4.0	2.0	63	4.0	2.0	0.0
281	T J DUVAL	8 78	6.9	102	81	38	48	0.00	0.00	16.0	2.0	4.0	1.0	27	6.0	4.0	14.2
283	S DANIELS	8 78	6.4	53	36	10	9	0.00	0.02	4.0	0.0	3.0	1.0	14	3.0	4.0	4.4
285	BERNARNINA	8 78	7.8	261	172	14	4	0.20	0.00	2.0	0.0	59.0	5.0	127	14.0	1.0	0.0
286	BISHOP MEMORIAL CHURCH	10 78	6.2	102	83	17	20	0.00	0.01	5.0	2.0	10.0	3.0	12	2.0	10.0	24.4
287	GILBERT MILES	10 78	7.6	279	194	21	33	0.10	0.00	10.0	2.0	50.0	3.0	118	6.0	4.0	1.7
288	W H SOUDER	10 78	6.2	60	80	9	15	0.80	0.07	3.0	2.0	7.0	3.0	12	14.0	4.0	0.8
289	W M SNOWA	12 78	6.6	36	3	18	9	0.00	0.00	4.0	0.0	2.0	0.0	14	5.0	3.0	0.8
290	JOHN TORIN JR	12 78	6.3	107	53	17	16	0.00	0.00	5.0	1.0	8.0	2.0	14	21.0	7.0	11.1
291	WILLIAM JENKINS	12 78	7.0	127	121	40	35	0.10	0.00	11.0	2.0	9.0	1.0	28	10.0	13.0	7.0
292	RUTH REYNOLDS	12 78	6.8	72	46	20	19	0.00	0.01	6.0	1.0	5.0	1.0	19	7.0	7.0	6.2
293	MARGARET MOORE	12 78	8.0	282	215	42	38	0.30	0.02	9.0	4.0	54.0	7.0	143	17.0	11.0	0.0
294	MICHAEL GLEASON	10 78	6.6	70	57	21	34	0.30	0.03	12.0	1.0	3.0	3.0	28	2.0	4.0	4.9
295	WILLIAM W TEMPLE	10 78	6.7	92	67	37	43	0.00	0.00	14.0	2.0	2.0	3.0	32	9.0	6.0	3.1
296	HORACE LEWIS	10 78	6.3	28	22	12	9	0.00	0.00	4.0	0.0	2.0	1.0	14	1.0	5.0	0.0

NOTE--ALL ZEROS (00.00) - ANALYSED, NOT DETECTED; ALL NINES (99.99) - COULD NOT BE STORED, REFER TO ANALYSIS

VIRGINIA STATE WATER CONTROL BOARD

BUREAU OF SURVEILLANCE AND FIELD STUDIES

DATE 05/28/80

SUMMARY OF GROUNDWATER QUALITY ANALYSES FOR HENRICO COUNTY

PAGE 9

SWCH NO	OWNER AND/OR PLACE	DATE SAMP	PH	SPEC COND	T-DIS SOLID	HARDNESS TOTAL	CA,MG	FE	MN	CA	MG	NA	K	ALK	SO4	CL	NO3
297	MARGARET MC DANIEL	10 78	6.4	30	29	10	12	0.00	0.00	5.0	0.0	2.0	1.0	16	1.0	4.0	0.0
298	ELVIN COSBY	10 78	6.8	84	64	30	34	0.20	0.01	12.0	1.0	6.0	2.0	31	2.0	6.0	6.2
299	IRENE P COSBY	10 78	7.0	122	98	52	54	0.10	0.00	22.0	0.0	7.0	1.0	53	2.0	14.0	1.3
300	ROBERT L WHITE	10 78	6.8	86	102	30	31	0.30	0.02	11.0	1.0	9.0	2.0	38	1.0	8.0	1.4
302	M FRANGER	3 78	7.3	158	115	66	17	0.04	0.00	2.0	3.0	4.0	2.0	10	28.0	9.5	
303	D POORE	4 79	6.0	82		24	22	0.00	0.00	7.0	1.2	0.0	0.8	10	6.0	4.0	15.1
312	WESTWOOD RACQUET CLUB	6 79	7.4	156	82	53	39	0.00	0.00	14.0	1.2	4.0	1.3	21	34.0	9.0	1.9

NOTE--ALL ZEROS (00.00) - ANALYSED, NOT DETECTED: ALL NINES (99.99) - COULD NOT BE STORED, REFER TO ANALYSIS

GLOSSARY OF TERMS

ALLUVIUM:	A general term for sediments deposited during recent geologic time by a stream or other body of water.
AQUICLUDE:	A geologic formation, group of formations, or part of a formation, which is not permeable enough to transmit ground water.
AQUIFER:	A geologic formation, group of formations, or part of a formation capable of supplying water to wells and springs in usable quantities. An aquifer is unconfined (water table) or confined (artesian) depending on whether the ground water level is at atmospheric pressure or greater than atmospheric pressure due to the presence of an overlying, confining geologic formation (aquiclude or aquitard).
AQUITARD:	A formation that partially restricts ground water flow, but will not yield water to a well.
ARTESIAN AQUIFER:	A confined aquifer in which ground water rises in a well above the point at which it is found in the aquifer.
ARTESIAN WELL:	A well in which the water rises under artesian pressure above the top of the aquifer the well penetrates, but does not necessarily reach the land surface.
BACK SWAMP DEPOSITS:	Thin layers of silt and clay deposited in the flood basin behind the natural levees of a river or distributary.
BASE EXCHANGE:	The reversible replacement of certain ions by others, without loss of crystal structure.
BATHOLITH:	A stock-shaped or shield-shaped intrusive mass of igneous rock.
BEDDING PLANE:	The division plane in sedimentary or stratified rocks which separates the individual layers, beds, or strata.
BEDROCK:	A general term for the rock which lies below the soil or other unconsolidated sediments.

BIOTITE: A generally black, dark brown, or dark green rock forming mineral of the mica group: $K(Mg, Fe^{+2})3\ (Al, Fe^{+3})Si_3O_{10}(OH)_2$.

BLOCK FAULTING: A type of normal faulting in which the earth's crust is divided into structural (fault) blocks of different elevations and orientations.

CALCITE: A common, usually white, rock forming mineral consisting of calcium carbonate ($CaCO_3$).

CAPILLARY FRINGE: The zone of partial or complete saturation directly above the water table in which water is held in the pore spaces by capillarity.

CATACLASTIC TEXTURE: A texture in a dynamically metamorphosed rock produced by severe mechanical crushing and differential movement of the component grains and characterized by granular, fragmentary, deformed, or strained mineral crystals flattened in a direction at right angles to the mechanical stress.

CEMENT: Chemically precipitated mineral material that occurs in spaces among the individual grains of a consolidated sedimentary rock, thereby binding the grains together as a rigid, coherent mass.

CHANNEL DEPOSITS: An alluvial deposit in a stream channel, especially, one in an abandoned cutoff channel or where the transporting capacity of the stream is insufficient to remove material supplied to it.

CLASTIC ROCK: A consolidated sedimentary rock composed of broken fragments that are derived from preexisting rocks, e.g. sandstone, conglomerate, or shale, etc.

CLAY: A rock or mineral fragment or a detrital particle of any composition often a crystalline fragment of a clay mineral, smaller than silt having a diameter of less than 1/256 mm.

COLIFORM: Designating, of, or like the aerobic bacillus normally found in the colon.

CONE OF DEPRESSION: A depression in the potentiometric surface of a body of ground water that has the shape of an inverted cone and develops around a well from which water is being withdrawn. It defines the area of influence of a well.

CONFINING BED: A bed which overlies or underlies an aquifer and which, because of low permeability relative to the aquifer, prevents or impedes upward or downward loss of water and pressure. An aquitard or aquiclude. (See aquifer)

CONFINED WATER: Water under artesian pressure. Water that is not confined is said to be under water table conditions.

CONGLOMERATE: A sedimentary rock, a significant fraction of which is composed of rounded pebbles and boulders; the lithified equivalent of a gravel.

CONSOLIDATED: A rock that is firm and rigid in nature due to the natural interlocking and/or cementation of its mineral grain components. The reverse is unconsolidated.

CONTINENTAL RISE: Submarine surface beyond base of continental slope, generally with gradient less than 1 to 1000, occurring at depths from about 1373 to 5185 m and leading down to abyssal plains.

CONTINENTAL SHELF: Gently sloping shallowly submerged marginal zone of the continents extending from the shore to an abrupt increase in bottom inclination; greatest average depth less than 183 meters, slope generally less than 1 to 1000.

CONTOUR (Topographic): An imaginary line or surface along which a certain quantity, otherwise variable, has the same value, e.g. an elevation line, structure contour.

CROSS-SECTION: A diagram or drawing that shows features transsected by a given plane; e.g. geologic features such as geologic structure.

CRYSTALLINE ROCK: Rock consisting of minerals in an obvious crystalline (having regular molecular structure) state.

DARCY: A standard unit of permeability, equivalent to the passage of one cubic centimeter of fluid of one centipoise viscosity flowing in one second under a pressure differential of one atmosphere through a porous medium having an area of cross-section of one square centimeter and a length of one centimeter.

DELTA: The low, generally triangular shaped, nearly flat, alluvial tract of land deposited at or near the mouth of a river.

DIABASE DIKE: A tabular igneous intrusion made of labradorite and pyroxene that cuts across the planar structures of the surrounding rock.

DIAGENETIC: Pertaining to that process involving physical and chemical changes in sediment after deposition that converts it to consolidated rock.

DIP: The maximum angle at which a rock bed is inclined from the horizontal.

DISTRIBUTARY: An irregular, divergent stream flowing away from the main stream and not returning to it, as in a delta or on an alluvial plain.

DRAWDOWN: Vertical distance between the static water level and the pumping water level of a well.

EROSIONAL UNCONFORMITY: An unconformity made manifest by erosion, or a surface that separates older rocks that have been subjected to erosion from younger sediments that cover them.

ESTAURINE DEPOSITS: A sedimentary deposit laid down in the seaward end or the widened funnel-shaped tidal mouth of a river valley where freshwater mixes with and measurably dilutes seawater and where tidal effects are evident.

EUTECTONIC: Gradual structural movements in the earth's crust noted by broad uplifting or subsidence in a region.

EVAPOTRANSPIRATION: The combined discharge of water to the air by direct evaporation and plant transpiration.

FAULT: A fracture or fracture zone along which there has been movement of two rock masses relative to one another parallel to the fracture. The movement may be a few inches or many miles.

FLOOD PLAIN: The strip of relatively-smooth land adjacent to a river channel and built of alluvium carried by the river during floods. The flood plain is covered by water when the river is in flood.

FLUVIAL: Of or pertaining to a river or rivers.

FOLIATION: A general term for a planar arrangement of textural or structural features in any type of rock.

FORMATION: The fundamental rock-stratigraphic unit for local classification of rocks. A mappable body of rock with a certain degree of lithologic homogeneity.

GEOHYDROLOGY: Referring to the hydrologic or flow characteristics of subsurface waters in relationship to geology. (syn: ground water hydrology)

GLAUCONITE: A dull green, amorphous, and earthy or granular mineral of the mica group: $(K, Na)(Al, Fe^{+3}, Mg)_2 (Al, Si)_4O_{10}(OH)_2$.

GNEISS: A foliated rock formed by regional metamorphism in which bands or lenticles of granular minerals alternate with bands and lenticles in which minerals having flaky or elongate prismatic habits predominate.

GPD: Gallons per day.

GRABEN: A block of the earth's crust, bounded by faults on its long sides, which has dropped relative to surrounding rocks.

GRAVEL: An unconsolidated, natural accumulation of rounded rock fragments with a diameter greater than 2 mm.

GROUND WATER: Water beneath land surface in the zone of saturation and below the water table.

HORNBLENDE: The commonest mineral of the amphibole group: $Ca_2Na(Mg, Fe^{+2})_4(Al, Fe^{+3}, Ti)(Al, Si)_8$.

HYDRAULIC CONDUCTIVITY: The permeability coefficient; the rate of flow of water in gallons per day through a cross section of one square foot under a unit hydraulic gradient, at the prevailing temerature or adjusted for a temperature of 60°F.

HYDRAULIC GRADIENT: In an aquifer, the rate of change of pressure head per unit of distance of flow at a given point in a given direction.

HYDROGEOLOGY: The science that deals with subsurface waters and related geologic aspects of surface waters.

HYDROLOGY: The science that studies the waters of the earth.

HYDROSTATIC HEAD: The height of a vertical column of water, the weight of which, if of unit cross section, is equal to the hydrostatic pressure at a point: static head as applied to water.

INFILTRATION: The flow or movement of water into the subsurface soil and rocks.

IGNEOUS ROCKS: Rocks formed by the cooling and crystallization of molten or partly molten material.

IMPERMEABLE: Having a texture which does not allow perceptible movement of water through rock.

INTERSTICES: The openings or spaces between fragments and grains in a soil or rock. In an aquifer they are filled with water.

INTRUSIVE: Refers to igneous rocks which have penetrated into or between older rocks while molten but have solidified before reaching the surface.

ION: An electrically charged atom or group of atoms. A cation has a positive charge, an anion a negative charge.

LEVEE DEPOSITS: A stream deposited enbankment along a river or watercourse.

MARL: A general term for unconsolidated deposits composed of clay and calcium carbonate.

MAGMATIC: Pertaining to naturally occurring molten rock material, generated within the earth and capable of intrusion and extrusion, from which igneous rocks are thought to have been derived through solidification and related processes.

METAMORPHIC ROCKS: Any rock derived from pre-existing rocks by mineralogical, chemical, and structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical enviornment at depth within the earth's crust.

METAVOLCANICS:	Metamorphosed volcanic rocks.
MUSCOVITE:	A mineral of the mica group: $KAl_2(Al, Si_3)O_{10}(OH)_2$.
NONFLOWING ARTESIAN WELL:	An artesian well in which the head is not sufficient to raise water to the land surface at the well site.
NORMAL FAULT:	A fault in which the hanging wall appears to have moved downward relative to the footwall.
OROGENIC:	Pertaining to the process of formation of mountains.
PARAMETER:	Any measurable characteristic of a sample or population.
PEGMATITE DIKE:	A tabular igneous intrusion made up of exceptionally coarse grained material with interlocking crystals.
PERCOLATION:	Movement of water through the interstices of rocks or soils except movement through large openings such as solution channels.
PERMEABILITY:	The ability of a rock to transmit water per unit of cross-section.
POINT BAR DEPOSITS:	Series of low, arcuate ridges of sand and gravel developed on the inside of a growing meander by the slow addition of individual accretions accompanying migration of the channel toward the outer bank.
POROSITY:	The ratio of the volume of the openings in a rock to the total volume of the rock.
POTENTIOMETRIC SURFACE:	An imaginary surface representing the static head of ground water and defined by the level to which water will rise in a well.
PROGRADATIONAL DELTA:	A delta built forward or outward toward the sea by river deposition.
RECHARGE:	The addition of water to an aquifer by natural infiltration or artificial means.
REGRESSIVE:	Said of deposits laid down during the retreat or contraction of the sea from land areas.

ROCK:	Any naturally formed, consolidated, or unconsolidated material (but not soil) composed of two or more minerals, or occasionally of one mineral, and having some degree of chemical and mineralogic constancy.
RUNOFF:	That part of precipitation that appears in surface streams.
SAND:	A rock fragment ranging in diameter from 1/16 to 2 mm.
SAPROLITE:	Soft, clay-rich rock formed by weathering and decomposition of igneous and metamorphic rocks. Much of the relic structure of the original rock may still be present; however, the minerals comprising the rock have been altered.
SCHIST:	A strongly foliated crystalline rock formed by dynamic metamorphism.
SEDIMENT:	Solid, fragmental, weathered rock material borne and deposited by water, air or ice.
SEDIMENTARY ROCKS:	Usually-stratified formations consisting of products of weathering by action of water, wind, ice, etc. (i.e., sand, sandstone, clay, shale, etc.).
SILT:	A rock fragment or detrital particle ranging in diameter from 1/256 to 1/16 mm.
SPECIFIC CAPACITY:	The rate of discharge of a water well per unit of drawdown commonly expressed in gallons per minute per foot.
STATIC WATER LEVEL:	That water level of a well that is not being affected by withdrawal of ground water.
STRUCTURE:	The general disposition, attitude, arrangement, or relative positions of the rock masses of a region or area, also referred to as "structural geology".
TECTONISM:	Crustal instability.
TERRACE DEPOSITS:	Deposits of alluvium (clay, silt, sand, gravel, or cobbles) which occur along the margin and above the level of a body of water, marking a former water level.

TERRIGENOUS: Land derived.

TOPOGRAPHY: The relief and form of a land surface.

TRANSGRESSIVE: Deposits laid down during the advance or extension of the sea over land areas.

TRANSPIRATION: The process by which water absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface.

TRANSMISSIVITY: In an aquifer, the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width under a unit hydraulic gradient.

UNCONFINED AQUIFER: An aquifer having a water table; an aquifer containing unconfined ground water.

UNCONSOLIDATED: A sediment that is loosely arranged or unstratified, or whose particles are not cemented together.

VAN DER WAALS' FORCES: Weak attractive forces between electrically neutral atoms and molecules.

VOLCANISM or VULCANISM: Volcanic power or activity, including all natural processes resulting in the formation of volcanoes, volcanic rocks, lava flows, etc.

WATER WELL: A man-made excavation that allows the extraction of water from the zone of saturation or that yields useful supplies of water. The well may be drilled, dug, excavated, or jetted.

WATER TABLE: The surface between the zone of saturation and the zone of aeration; that surface of a body of unconfined ground water at which the pressure is equal to that of the atmosphere.

REFERENCES

American Geological Institute, 1976. Dictionary of Geologic Terms, Anchor Press, Garden City, New Jersey.

Berry, L. G. and Mason, Brian, 1959. Mineralogy: Concepts, Descriptions, Determinations, W. H. Freeman and Company, San Francisco.

Bloomer, R. O., 1939. Notes on the Petersburg Granite: Virginia Geologic Survey Bulletin 51-F, p. 137-145.

Bobyarchick, Andy R. and Glover, Lynn III, 1979. Deformation and Metamorphism in the Hylas Zone and Adjacent Parts of the Eastern Piedmont in Virginia, Geologic Society of America Bulletin, Part 1, V. 90, p. 739-752, 11 figures, 1 table, August, 1979, Doc. No. 90808.

Brown, P. M., Miller, J. A., and Frederick, M. S., 1972. Structural and Stratigraphic Framework and Spatial Distribution of Permeability of the Atlantic Coastal Plain, North Carolina to New York. U. S. Geological Survey Professional Paper 796.

Cederstrom, D. J., 1957. Geology and Groundwater Resources of the York-James Peninsula, Virginia. U. S. Geological Survey Water - Supply Paper 1361.

Clay, John W., 1975. Soil Survey of Henrico County, Virginia, USDA and V.P.I. and S.U.

Conley, J. F., 1978. Geology of the Piedmont of Virginia - Interpretations and Problems in Contributions to Virginia Geology - III: Virginia Division of Mineral Resources Publication 7, p. 115-149.

Conservation and Economic Development, Dept. of. "Geologic Map of Virginia" Division of Water Resources, 1963.

Cook, Frederick A., Kaufman, Sidney; Oliver, Jack E., and Hutcher, Robert D., Jr., 1979. Thin-skinned Tectonics in the Crystalline Southern Appalachians, COCORP Seismic - Reflection Profiling of the Blue Ridge and Piedmont in Geology, V. 7, p. 563-567, December, 1979

Cornet, Bruce, 1977. The Palynostratigraphy and Age of the Newark Supergroup, Unpublished Ph.D. dissertation, University Park, Pa.

Daniels, P. A., Jr. and Onuschak, Emil, Jr., 1974. Geology of the Studley, Yellow Tavern, Richmond and Seven Pines Quadrangles, Virginia, Virginia Division of Mineral Resources Report of Investigations 38.

Darton, N. H., 1911. Economic Geology of Richmond, Virginia and Vicinity: USGS Bulletin 483.

Davis, Stanley N. and Dewiest, Roger J., 1966. Hydrogeology. John Wiley and Sons, Inc., New York.

Dischinger, James B., Jr., 1979. Late Mesozoic and Cenozoic Stratigraphic and Structural Framework Near Hopewell, Virginia, Masters Thesis for the University of North Carolina at Chapel Hill.

Division of State Planning and Community Affairs. "Data Summary" Henrico County, January, 1973.

Ellison, Russell P., III and Masiello, Remo A., 1979. Groundwater Resources of Hanover County, Virginia, SWCB Planning Bulletin 314.

Environmental Protection Agency, U. S., 1974. Manual of Individual Water Supply Systems, Office of Water Programs, Water Supply Division.

Freeze, R. Allen and Cherry, John A., 1979. Groundwater, Prentice Hall, Inc., Englewood Cliffs, New Jersey.

Gary, Margaret, McAfee, Robert Jr., Wolf, Carol L., 1972. Glossary of Geology, American Geological Institute, Washington, D. C.

Goodwin, B. K., 1970. Geology of the Hylas and Midlothian Quadrangles, Virginia. Virginia Division of Mineral Resources Report of Investigations 23.

Goodwin, B. K., 1980. Geology of the Bon Air Quadrangle, Virginia: Virginia Division of Mineral Resources Publication 18, text and 1:24,000 scale map.

Johnson, Edward E., Inc., 1955 and 1974. Groundwater and Wells. Edward E. Johnson, Inc.

Mixon, R. B. and Newell, W. L., 1978. The Faulted Coastal Plain Margin at Fredericksburg, Virginia, The Guidebook for the Tenth Annual Virginia Geology Field Conference.

Murphy, J. Roy, 1979. Groundwater Resources of Loudoun County, Virginia, SWCB Planning Bulletin 315.

Siudyla, E. A., Berglund, T. D., and Newton, V. P., 1977. Groundwater of the Middle Peninsula, Virginia. SWCB Planning Bulletin 305.

Sterrett, R. McChesney and Hinkle, Kenneth R., 1980. Ground Water Resources of Albemarle County, Virginia, SWCB Planning Bulletin 326.

Teifke, R. H., 1973. Geologic Studies, Coastal Plain of Virginia, Parts I and II. Virginia Division of Mineral Resources, Bulletin 83, Parts 1 and 2.

Virginia Division of Water Resources, 1971. Groundwater Henrico County, Virginia Preliminary Basic Data Bulletin 36P.

Ward, L. and Blackwelder, B. W., 1980. Stratigraphic Revision of Upper Miocene and Lower Pliocene Beds of the Chesapeake Group, Middle Atlantic Coastal Plain: Geological Survey Bulletin 1482-D.

VIRGINIA STATE WATER CONTROL BOARD
P. O. Box 11143, 2111 North Hamilton Street
Richmond, Virginia 23230
(804) 257-0056

1 **Southwest Regional Office**
408 East Main Street
P. O. Box 976
Abingdon, VA 24210
(703) 628-5183

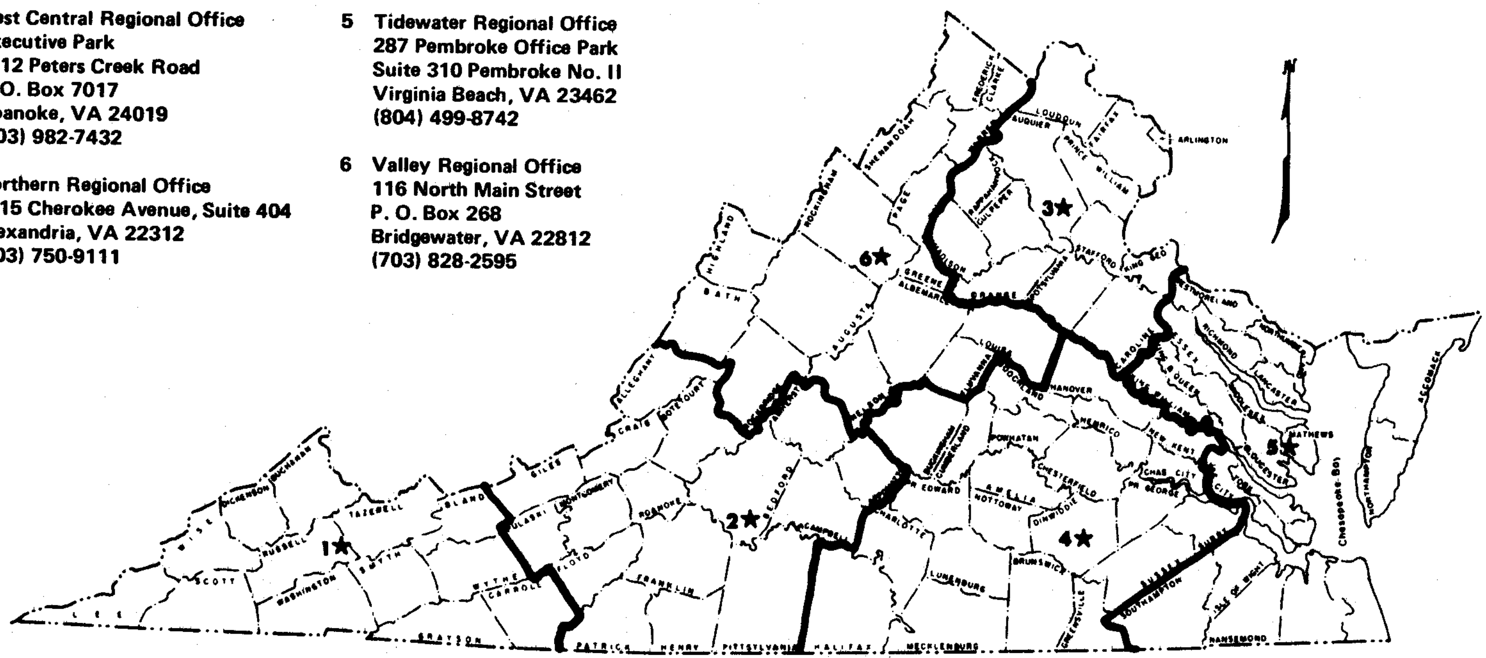
2 **West Central Regional Office**
Executive Park
5312 Peters Creek Road
P. O. Box 7017
Roanoke, VA 24019
(703) 982-7432

3 **Northern Regional Office**
5515 Cherokee Avenue, Suite 404
Alexandria, VA 22312
(703) 750-9111

4 **Piedmont Regional Office**
4010 West Broad Street
P. O. Box 6616
Richmond, VA 23230
(804) 257-1006

5 **Tidewater Regional Office**
287 Pembroke Office Park
Suite 310 Pembroke No. II
Virginia Beach, VA 23462
(804) 499-8742

6 **Valley Regional Office**
116 North Main Street
P. O. Box 268
Bridgewater, VA 22812
(703) 828-2595



Source: Virginia State Water Control Board

End Flap


VIRGINIA
SIC SEMPER TYRANNIS
PERSEVERANDO